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A journal of stomatology; devoted to the advancement and dissemination of knowledge pertaining to the mouth and teeth, and to their relations to the body as a whole

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CILIATED EPITHELIUM IN A GRANULOMA

GUTHRIE McCONNELL

Research Institute of the National Dental Association, Cleveland, Ohio

CONTENTS

Introduction 197
The author's specimen 198
Report of the microscopic examination 198
Discussion of the origin of the epithelium 201
Literature cited 201

INTRODUCTION

In a discussion of periapical cysts and granulomas, a never-failing point of interest is the origin of the epithelium that is frequently found either as nests or as a lining membrane. The type of cell usually found is the squamous epithelium. The majority of observers believe that these cells originate in the embryonal rests, or remnants, of the primary enamel organ, such as are not infrequently found in the alveolar periosteum (peridental membrane). Such a belief would seem to be a very reasonable one, since there is every opportunity, in the development of the enamel, for portions of the enamel organ to become detached and lie dormant for many years. So long as there is no cause of irritation, such portions may remain quiescent indefinitely. It is a well recognized fact that there are many instances in other parts of the body where portions of tissue have become separated, during embryonic life, from their normal relationships. Cohnheim's theory of cancer formation, and Ribbert's modification of it, are based on changes, occurring late in life, in these "rests."

Grawitz (2) claims that, in the development of periapical cysts, a sinus originally communicates with the periapical lesion and that the epithelium penetrates along this tract. Eventually the sinus heals, the epithelium disappears and all evidences of communication with the surface vanish, thus leaving an isolated cyst lined by squamous epithelium. Adloff (1) accepts the theory of embryonal

rests as the usual cause, but thinks that Grawitz's theory must be taken into consideration, for Adloff found, in two cysts in the neighborhood of the antrum of Highmore, ciliated columnar epithelium similar to that of the mucous membrane lining the cavity. Although no communication with the antrum is mentioned, the logical conclusion is that, in the two instances quoted, the epithelium had come from that source.

THE AUTHOR'S SPECIMEN

In the specimen now being reported, no history is obtainable as to its formation or location, for the tooth was but one of some twenty, with attached granulomas, that were sent to this Institute for histological examination. There was nothing in the gross specimen to suggest that it was of special interest, and it was not until the microscopic examination was made that the peculiar character of the specimen was noted. By that time the body of the tooth had been disposed of, and its physical characteristics could not, therefore, be determined. The tooth was single rooted and, attached to the apex, was a small mass of solid tissue about 2 mm. by 4 mm. in size on its surface. The specimen was decalcified, imbedded in celloidin, cut, and stained in hematoxylin and eosin, and Van Gieson and Mallory's anilin blue.

Report of the microscopic examination

Continuous with the alveolar periosteum (peridental membrane) is a well defined zone of dense connective tissue, the fibres of which describe an arc roughly approximating that of the apex of the tooth (*fig. 1*). Through this tissue is a very high grade of infiltration by cells containing round or somewhat oval nuclei staining quite uniformly. Wherever the protoplasm is evident, it is noted that the nuclei are situated eccentrically. The general appearance is that of plasma cells. A few well-formed capillary blood vessels are present in this area. No polymorphonuclear leucocytes were noted.

The portion in immediate contact with the tooth, and partially enclosed by the fibrous wall, is of a different structure; it contains young growing connective tissue in which the cells are much more conspicuous than the intercellular material. Many plasma cells and

many leucocytes are present, as well as numerous red blood cells lying free within the tissues. Undeveloped capillary blood vessels are quite plentiful.

The two areas described constitute about one-half of the specimen. The remaining portion shows a very different condition. In it there is one section that contains a very great number of small capillaries

FIG. 1. LOW POWER PHOTOGRAPH, SHOWING, AT *A*, THE AREA COVERED BY CILIATED EPITHELIUM (*fig. 2*)

supported by a net-work of fine connective-tissue fibres much infiltrated by plasma cells and leucocytes. Adjacent to this, and extending into the other half of the specimen, are numerous elongated intercommunicating strands of cells sharply delimited from the surrounding tissues. The edges of these strands are composed of closely packed, long, spindle-shaped cells containing rather deeply stained nuclei of similar form. As the interior of the strands are approached,

the cells become larger and more oval, a greater amount of protoplasm is visible, and the nuclei also become more oval and stain but slightly. The characteristics are those of squamous epithelium.

The areas between the strands show a dense massing of plasma cells with a few leucocytes. A few of these latter cells are scattered through the epithelial strands. This type of epithelium extends all

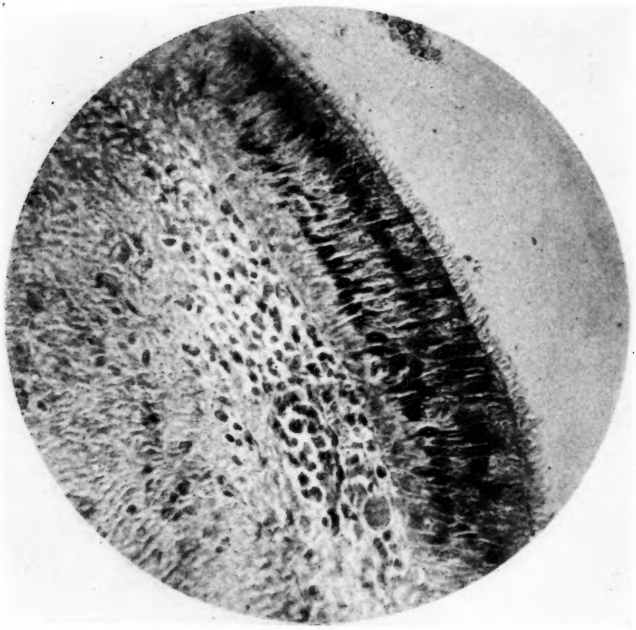

FIG. 2. CILIATED EPITHELIUM IN THE GRANULOMA (*fig. 1*)

the way to the distal surface of the granuloma, to the part which it is expected would be in contact with the alveolar process.

It is at this point that the most interesting feature of the specimen is found. *Resting on the distal margin of the granuloma is a well defined layer of ciliated columnar epithelium* (*fig. 1, A*). This structure rests upon a definite basement membrane, and its cells, extending at right angles, contain long, oval, deeply staining nuclei (*fig. 2*). The free surface shows very clearly well defined cilia. One end of this mem-

brane is in immediate contact with the portion of squamous epithelium that extends deeply into the granuloma almost to the tooth.

The tooth itself presents certain abnormalities. The greater part of the surface shows quite extensive hypercementosis with small areas of slight absorption. The cementum, in one place close to the apex, has been absorbed completely and part of the dentin as well.

Discussion of the origin of the epithelium

For such a specimen as this, the difficulty of determining the source of the epithelium is due to lack of knowledge of the original location of the tooth. If the tooth came from the upper jaw, the possibility would have to be considered that the granuloma slowly penetrated the antrum of Highmore so that it came in contact with some of the ciliated epithelium of that cavity. A less likely possibility would be a penetration into the nasal cavity where similar epithelium occurs. If the tooth came from the lower jaw, however, the only source from which ciliated epithelium could be derived would be a remnant of the visceral arches or clefts. That such remnants do occur has been noted in numerous instances in which cysts lined with ciliated epithelium have been found near the angle of the jaw. These inclusions can be explained from a consideration of the embryonal conditions. The first visceral arch divides into an upper part, the maxillary arch, and a lower portion, the mandibular or jaw arch. The mandibular processes of the two sides are joined together anteriorly and constitute the inferior boundary of the mouth cavity.

The squamous epithelium that is so prominent in the specimen probably was derived from remnants of the primitive enamel organ contained in the alveolar periosteum.

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CALCIFICATION IN THE PULP OF TEETH AFFECTED BY PYORRHEA, WITH AN OUTLINE OF A METHOD OF DEMONSTRATING THE PRESENCE OF TUBULES IN THE CALCIFIED PORTIONS OF SUCH PULP

ALPHONSE LANG AND GUTHRIE McCONNELL

Research Institute of the National Dental Association, Cleveland, Ohio

CONTENTS

Introduction 203
Observations by the authors 207
Findings 207
Technic to show the tubular structure of calcified masses in the pulp tissue 212
Literature cited 213

INTRODUCTION

In a study of the process of calcification certain factors have to be considered in order clearly to appreciate the changes that take place. The calcium salts must come from the blood, where they are held in solution or suspension by the proteins, either as the carbonate and phosphate themselves, or as calcium ion-protein compounds, or both. Except for the formation of normal bone and dentin, calcium salts are not deposited in tissues that retain their full vitality. If, however, the tissues are partially or completely dead, deposition of lime salts is not an uncommon happening. One of the best examples of this is the calcification that occurs in the degenerated and caseous areas of tuberculosis in both lungs and lymph nodes.

Inasmuch as the suspension or solution of the calcium salts in the blood is unstable, Wells (3) concludes that the deposit of these salts in degenerated tissues depends upon one or more of the following conditions:

(1) Increased alkalinity or decreased content of carbon dioxide in the degenerating tissues, causing precipitation of the inorganic salts in the fluids slowly seeping through such tissues.

(2) Utilization of the proteins of the fluids by the starved tissues so completely, because of the slow passage of the fluids through such tissues, that the calcium cannot continue to be held in solution.

(3) The formation, within the degenerated tissue, of a substance or substances having special affinity for calcium.

(4) Production of a physical condition favoring local absorption of salts, the least soluble salts accumulating in excess.

When the composition of the inorganic salts in calcified portions of tissues is determined, it seems to be practically uniform, whether the salts are laid down under normal conditions (ossification) or as the result of pathological changes. The main difference seems to be lack of regularity of formation in the deposit in the broken down tissues. These calcification changes may be found wherever the necrotic portions are so large, or so situated, that they cannot be absorbed.

A frequent site for the deposit of calcium salts seems to be the pulp cavity of teeth. This would indicate that, in such instances, the conditions necessary for calcification have been present. The amount of degenerated tissue in the dental canal cannot be large; but the dental pulp is so located that absorption cannot well take place, for, with the possible exception of multirooted teeth, there is no collateral circulation.

In discussing the deposits of calcium salts that occur in the pulp, Black (1) makes a convenient classification of such deposits into two groups. He divides them into calcifications that are attached to the walls of the pulp chamber, and those that are not thus attached.

The attached calcifications may be physiological, for they appear to result from lesions on the surface of the teeth, such as abrasions and erosions. These surface changes cause the formation of secondary dentin, which is usually most marked in the area underlying the lesion. Such secondary dentin is more or less continuous with the primary dentin, and its structure reproduces to a greater or less degree that of the normal. By its formation, a layer of dentin approximating that which is normal is interposed between the pulp and the exposed surface of the tooth.

The unattached calcifications in the dental canal are particularly interesting at present. What processes are necessary for deposition of calcium salts within the pulp tissue itself? The very fact that

these salts are deposited denotes that a pathological condition is or was present in that tissue. Abnormal calcification in other parts of the body occurs in tissues whose vitality has been impaired. The question then arises as to the causation of abnormal changes in the pulp. This structure is composed of a somewhat embryonal type of connective tissue, which contains arteries, veins and nerves, and which is subject to the laws that control other parts of the body.

One of the very common conditions of the teeth, which may arise from many causes, is hyperemia of the pulp. A frequent cause is irritation of dentinal fibrils at the beginning of caries, or by a filling over a pulp that is nearly exposed. If a similar change elsewhere is examined, it will be found that, in cases of hyperemia, there is a very regular sequence of events. Ordinarily the tissue quickly returns to the normal when the irritation ceases. If, however, the cause is not removed, it will be noted that the blood eventually tends to remain, to stagnate. The veins will become more and more dilated, and fresh blood will be unable to find free access. Consequently there will be interference with nutrition, and death of a few or of many cells will occur, due to this lack of food and of proper oxygenation. The cells undergo gradual transition from the normal through fatty metamorphosis to final necrosis and death. When the cells lose their vitality, the primary requisite for the deposit of calcium salts is fulfilled. As these deposits are not the result of a normal physiological process of repair, they do not show any regular outline or structure so far as macroscopic appearance is concerned.

The histories of the cases in which the teeth show these pulp stones indicate that there has been a slowly developing lesion. The important etiological factor appears to be a mild irritation continued over a long period. Given this combination, calcium salts will be deposited. Of the chronic diseased conditions of the mouth, one of the most common is probably pyorrhea alveolaris. As to its etiology we are not at present concerned, but its clinical course is of importance. It is primarily an inflammatory condition, characterized by degenerative changes leading to a cellular necrosis of the retentive structures of the teeth, the peridental membrane, an atrophy of the alveolar walls, and a chronic hyperemia of the gums. Although the process occasionally is acute in its course, the usual history is that of marked chronicity.

Judging from chronic inflammatory changes elsewhere in the body, it is but natural to suppose that, as a result of the chronic irritation present around the tooth, abnormal changes must be taking place within it. The peridental membrane, which is more or less extensively involved, has a blood supply derived from the same source as that of the pulp. The blood supply of the pulp undergoes alterations and, as already pointed out, the usual result of chronic hyperemia is death of some part of the tissue. The surroundings are such that absorption of these areas is practically out of the question. There are present, then, all the conditions necessary for the deposit of calcium salts.

In addition to the chronic irritation secondary to extension of infection along the peridental membranes, a low grade inflammation of the pulp may result from carious conditions of the teeth. The work done by Collins (2) in this Institute, as well as that of others, shows that in carious teeth microörganisms can pass through the dentin into the canal before the caries has extended to the pulp itself. When the caries has been acute or even of normal rapidity, the chances are that secondary dentin will not be found (1). If, however, caries proceeds slowly, there will be a mild inflammatory reaction in the pulp, cells from various sources will make their appearance, and eventually many such cells will degenerate. Such an area may well be a focus for a deposition of calcium salts. As already stated, however, none of the teeth in this series showed any cavities.

According to observers in the past, the microscopic examination of these deposits has not shown any definite structure. Black states (1, p. 274): "On making sections for microscopical study, most of these calcifications are found to be homogeneous or clear calcifications. These are all non-tubular. These sometimes have threads of tissue which are not calcified, irregularly mingled in their substance."

If the histology of the pulp is considered, one of the most prominent structures is the layer of odontoblasts on the inner surface of the dentin. The function of the odontoblasts is analogous to that of the osteoblasts in bony tissue. These similar cells assemble the deposits of calcium salts and arrange them in an orderly manner, making dentin in one instance, bone in the other. If such cells are stimulated, there is but one way in which they manifest their activity, and that is by performing their special function. When the cells of a secreting organ

are stimulated, the result is an increased secretion from that organ. It can well be argued, a priori, that a chronic hyperemia of the pulp, continued for a long period, will bring about degenerative changes in certain cells. At the same time, the specialized cells in the immediate vicinity, in this case the odontoblasts, will be stimulated, in consequence of which an effort will be made by them to form dentin. The same thing happens when osteoblasts are stimulated. Inasmuch as the process is an abnormal one no regularity in formation would be expected. The fact that no tubules have been seen by previous observers in such pulp calcifications does not necessarily imply that tubules are not present. The Treponema pallidum has always been present in syphilis yet it was not until special staining methods were employed that it became easily recognizable.

OBSERVATIONS BY THE AUTHORS

In the examination of teeth that have been removed in cases of pyorrhea, there are frequently found, in the peridental membrane, small hard bodies of irregular shapes and evidently formed of calcium salts. This circumstance suggested a study of the pulp as found in such cases.

Findings

In the work done by Mr. Lang and upon which this paper is based, one hundred teeth were obtained from thirty-eight cases of pyorrhea. None of the teeth examined were carious. Their gross examination showed the surface of the cementum to be roughened, and in isolated areas this layer was entirely absent, thus exposing the dentin. In twenty of the teeth the pulp chamber was opened by drilling through the enamel and the pulp removed with a broach. This tissue was then teased out and examined under the microscope. Calcified masses were found distributed throughout eight of these pulps. An attempt was made to imbed these specimens and continue the examination, but it was not successful and they were discarded.

Of the remaining eighty teeth, cross and longitudinal sections, 5 mm. thick, were made and each was decalcified with 10 cc. of nitric acid (c.p.; sp. gr., 1.32) and 1 cc. of formalin (40 per cent) in 90 cc. of water. Each specimen was placed in a one-ounce bottle filled with

the fluid, kept in an incubator, at 37.5°C., for two to six hours, and shaken every hour during this treatment. After that the specimens were washed for twenty-four hours in running tap-water, hardened, dehydrated, and mounted in celloidin.

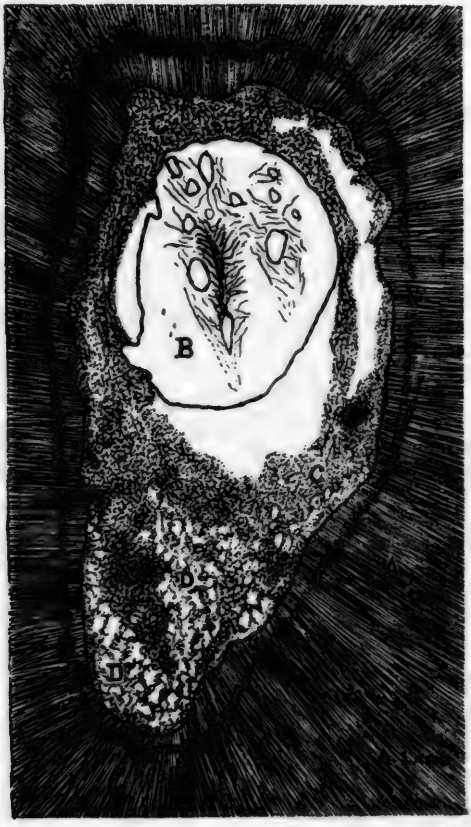

FIG. 1. DIAGRAM DRAWN, WITH CAMERA LUCIDA, OF A CROSS SECTION SHOWING A DENTINAL TUMOR IN THE PULP CAVITY

A.—Dentin. *B.*—Tumor. *C.*—Remnants of the pulp tissue. *D.*—Atrophied pulp tissue.

The teeth used for this purpose were uppers and lowers, with one two or three roots, taken from patients of both sexes whose ages ranged

from twenty to fifty years. Out of the eighty specimens prepared by the above process there were twenty in which calcified areas were found in the pulp. None of these showed any connection with the dentin, all apparently lying free in the pulp cavity. On examination by the ordinary methods these masses, irregular in shape, showed no definite structure. They appeared to be homogeneous masses, thus

FIG. 2. A CROSS SECTION OF A DENTINAL TUMOR IN PULP TISSUE
Note the tubules—16 mm.; ocular 10. Field A was taken with the high power (*fig. 3*).

conforming to the descriptions given by other observers. When however, the special method, as described later, was used, a very different picture was obtained. Of the calcified masses in these twenty teeth, each mass showed more or less *tubular structure*. These tubules were very irregular in form; sometimes they were interlocked in indefinite arrangements and giving off small branches, particularly

toward the terminal end. The structure is very definite but permanent mounts could not be made, for the Canada balsam used in mounting soon entered the tubules which then lost their ability to refract the light. They remained visible long enough to enable us to study and photograph them.

This formation can be explained satisfactorily on the theory that, during the degenerative changes in the cells, the odontoblasts are

FIG 3. HIGH POWER VIEW OF FIELD *A* (*fig. 2*), SHOWING A BUNDLE OF TUBULES IN THE TUMOR—4 MM.; OCULAR 10

stimulated to perform their normal function. The conditions essential for the deposition of calcium salts being present, the adjacent odontoblasts send out fibrils around which the salts are deposited and the tubules formed. As the location of such areas is distinctly abnormal, and the stimulation does not affect the layer of odontoblasts in a uniform manner, the natural result is the production of an irregu-

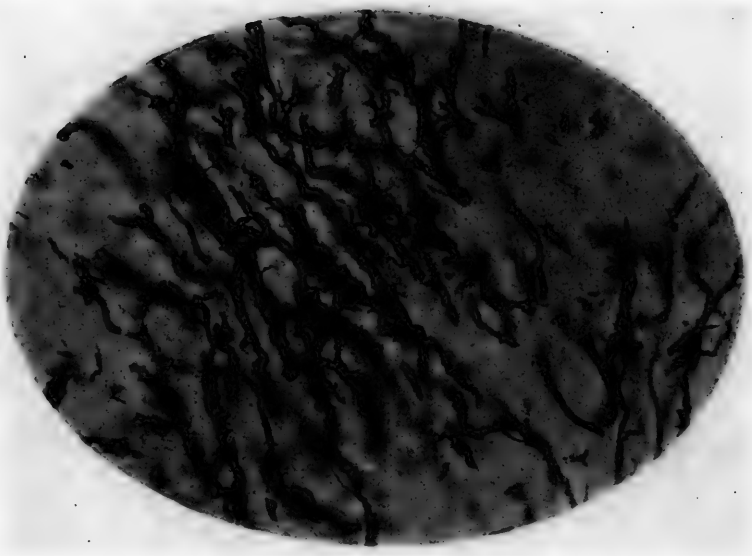

FIG. 4. A TUBULAR STRUCTURE IN A CALCIFIED MASS, SUSPENDED IN PULP TISSUE—4 MM.; OCULAR 10

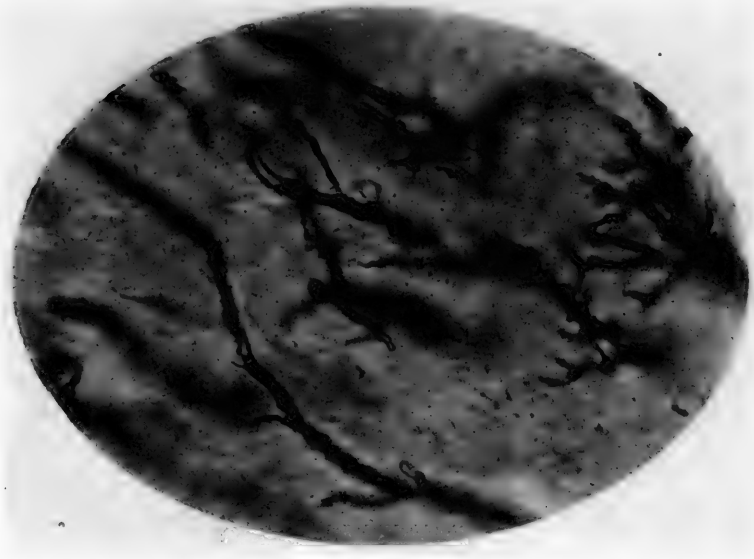

FIG. 5. A FIELD IN THE STRUCTURE SHOWN IN FIGURE 4, UNDER AN OIL-IMMERSION LENS—1.9 MM.; OCULAR 10

lar tubular structure. It is quite evident that these unattached calcified areas are secondary to chronic inflammatory lesions around the teeth, which set up a hyperemic condition of the pulp with subsequent degeneration and calcification. That tubuli may be found seems quite possible in view of the nearness of the odontoblasts.

In order that this work may be verified by others, a description of the method employed is added.

Technic to show the tubular structure of calcified masses in the pulp tissue

A: 1. Cut the specimen in sections about 5 mm. thick.

2. Decalcify in a solution of 90 cc. of distilled water, 10 cc. of nitric acid (c.p.; sp. gr. 1.32), and 1 cc. of formalin (40 per cent) at 37.5°C. from two to six hours with shaking every hour.

3. Wash in running tap-water for twenty-four hours.

4. Dehydrate successively in 50 per cent, 75 per cent, 95 per cent and 100 per cent alcohol for twenty-four hours.

5. Place in ether twelve hours.

6. Place in *thin* celloidin three days.

7. Place in *thick* celloidin three days.

8. Mount on block and evaporate in chloroform for four hours.

9. Place in 80 per cent alcohol till ready to cut.

B: 1. Place the section for at least ten minutes in distilled water to get rid of the alcohol.

2. Stain for five minutes in Delafield's hematoxylin.

3. Wash in tap-water.

4. Place in acid alcohol for ten seconds.

5. Place in ammonia-alcohol for ten seconds.

6. Place in alcohol (7 per cent) for ten seconds.

7. Place in aqueous solution of eosin (5 per cent) for thirty seconds.

8. Wash in 95 per cent alcohol till no more stain is given off.

9. Clarify in creosote.

10. Mount the section on a slide and remove the creosote with blotting paper.

11. Dehydrate in a few drops of 95 per cent alcohol and blot again.

12. Have cover-slip fixed with Canada balsam beforehand.

13. Now lay over the section a small piece of blotting paper saturated with ether, pressing down with a finger from ten to twenty seconds.

14. Remove the blotting paper and drop quickly the fixed cover-slip upon the section.

15. Press down the cover-slip lightly and observe the structure of the tubules under the microscope.

16. The specimen has to be photographed immediately, for the tubules are filled with Canada balsam in a short time.

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THE ORIGIN AND EVOLUTION OF THE HUMAN DENTITION[1]

A Palæontological Review

(*Continued*)

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PART II. STAGES OF ASCENT FROM THE PALEOCENE PLACENTAL MAMMALS TO THE LOWER PRIMATES[1]

CONTENTS

I. The primitive placental mammals of the Paleocene and Eocene Epochs, and the origin of their molar types 216
Origin of the placentals 216
Origin of the "tritubercular" upper molars of primitive placentals 218
Origin of omnivorous and herbivorous types of molars in the early placentals. 225
II. Introduction to the study of the evolution of the teeth in the Primates. Dependence of odontology upon palæontology and taxonomy, or classification according to kinship 229
III. The lemuroid Primates (Eocene to Recent) 232
Are the lemurs true Primates or pseudo-Primates? 232
Origin of the Primates 234
The primitive lemuroids (Notharctidæ) of the American Eocene 238
The Adapidæ of the Eocene of Europe 253
Origin of the Lemuridæ 257
Adaptive radiation of the dentition in the higher lemurs of Madagascar. "Habitus" and "heritage" 261
Summary and conclusions for Part II 267

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[1] Part I of this review was published on pages 89–183 (March issue) of this volume of the Journal of Dental Research.—(Ed.)

I. THE PRIMITIVE PLACENTAL MAMMALS OF THE PALEOCENE AND EOCENE EPOCHS, AND THE ORIGIN OF THEIR MOLAR TYPES

Origin of the Placentals

During the millions of years of the Age of Reptiles, when the dinosaurs were the "lords of the swamps and forests," the mammals, so far as the imperfect palæontological records show, remained small and inconspicuous. The multituberculates went on specializing to their extinction in the Paleocene epoch, but were never a prominent element of the Mesozoic fauna. The triconodonts apparently became wholly extinct in the Upper Jurassic and were not ancestral to any of the Cretaceous or existing marsupials. Most of the diversely specialized Jurassic trituberculates probably also died out, but some of the more primitive ones, such as *Amphitherium*, may have given rise, first, to the marsupials of the Upper Cretaceous and, secondly, to the placentals of the Age of Mammals.

The great series of placental orders is conspicuously absent from the record of the Age of Reptiles as it stands. Possibly they may have been evolving somewhere in the uplands, out of reach of the swarming reptiles of the swamps, and thus may have left their remains in upland deposits which, during the many millions of years since Mesozoic time, have all been completely eroded away (W. D. Matthew).

At the close of the Cretaceous, or soon afterward, the dinosaurs disappear from the record and, after a relatively brief interval, archaic placental mammals of several orders appear in the Paleocene of western North America and Europe. As they are already typical placentals and sharply differentiated from the Upper Cretaceous marsupials, they must have been evolving in some palæontologically unknown region from which they migrated into the known localities, chiefly in New Mexico and Montana; unless, by a highly improbable evolutionary miracle, they suddenly sprang into being from the more primitive marsupials.

In this connection it is necessary to consider whether the placental orders constitute a natural group, derived from a single family, or from closely related families, of pre-placentals, or whether the pla-

cental grade of organization has arisen independently and at different times from widely different sources. Wortman, in 1904, expressed the view that some of the placental orders, especially the Carnivora, had been derived directly from Cretaceous Metatheria, and an inspection of his context indicates that he had in mind particularly the group here classed as polyprotodont marsupials. Gidley, in 1919, suggested that "there is some evidence that the primates, and probably some other orders as well, have been derived independently from different though probably more or less closely related *pre-mammalian*[2] ancestral groups." Gidley did not specify what the evidence was for this view, which is a fine expression of his favorite "polyphyletic theory" applied on a large scale. The general problem of the origin of the placentals will be fully discussed by Matthew in his forthcoming memoir on the Paleocene faunas; so that it need only be stated here, that the present writer thoroughly accords with him in the opinion that most of, or probably all, the orders of placental mammals have been derived from related families of pre-placental mammals, which were in turn remotely allied with the ancestors of the Upper Cretaceous marsupials. At least it is a fact that, as we trace backward the history of various placental orders during Tertiary times, in all cases in which the record is adequate, the earlier forms tend toward or actually exhibit the following characters:

(1) Dental formula of adults: $I\frac{3}{3}$ $C\frac{1}{1}$ $P\frac{4}{4}$ $M\frac{3}{3}$; deciduous dental formula: $Di\frac{3}{3}$ $Dc\frac{1}{1}$ $Dp\frac{4}{4}$.

(2) Upper molars narrow anteroposteriorly, evenly trigonal, with moderate development of the external cingula.

(3) Lower molars have a well developed talonid, bearing a distinct hypoconid and entoconid.

(4) Angle of mandible not inflected; postglenoid process of squamosal not modified into an auditory bulla.

(5) General construction and foramina of the skull essentially as in the *Deltatherium*[3] type and differing in numerous points from the primitive marsupial type.

(6) Skeleton extremely primitive, lacking the pronounced arboreal specializations of the primitive marsupials.

[2] The italics are mine.—W. K. G.

[3] To be described by Matthew.

The placental mammals of the Paleocene formations of New Mexico belong to two successive faunas, the Puerco and Torrejon, which include, besides the last multituberculates, representatives of several archaic placental orders. The latter, for the most part, did not give rise to the modernized placental orders, but belonged to groups that died out in the Eocene. Nevertheless, these numerous archaic Paleocene mammals, such as the mesonychid creodonts, the condylarths, periptychids, tæniodonts and zalambdodont insectivores, are of immense value and importance, partly because they reveal the ways in which primitive dentitions with tritubercular upper molars evolved, on the one hand into the elaborate grinding mechanisms of herbivorous mammals and on the other hand into the efficient shearing and crushing dentitions of the creodonts; they also furnish invaluable collateral evidence on the origin of the dental construction of the later placental orders, such as the perissodactyls, artiodactyls, rodents and primates, which come into view either at the summit of the Paleocene (Tiffany formation) or at the base of the Lower Eocene. The Paleocene and Eocene placental mammals are represented in the American Museum of Natural History by great collections, numbering thousands of specimens, which deserve far more attention from odontologists than they have received, since they afford convincing proof of the enduring portion of the "Cope-Osborn theory"—that the diverse molar patterns of late mammals have been derived from the primitive tritubercular molar types of the Paleocene.

Origin of the "Tritubercular" Upper Molars of Primitive Placentals

Of the many known Paleocene mammals, *Palæoryctes* (described by Matthew in 1913), at first sight looks most like a direct descendant of one of the Jurassic trituberculates. The lower molars have the high, pricking, type of trigonid and the low, small, talonid, while its upper molars also have a narrow trigonal form suggesting the Jurassic Stylodontidæ; but, as Matthew has shown, the upper and lower molar patterns of this animal are apparently homologous with those of more normal tritubercular dentitions, such as that of *Didelphodus* (*fig. 45*) of the Lower Eocene. It also appears probable that, as *Palæoryctes* represents the zalambdodont, or centetoid, division of the insectivores,

FIG. 43. DENTITION OF *Palæorycles puercensis*. UPPER TEETH, ×5; LOWER TEETH, ×6. AFTER MATTHEW

The molar teeth of this minute Paleocene insectivore resemble those of the Jurassic trituberculates in some respects. (Compare Part I, p. 143.)

it is already tending toward the secondarily simplified, V-shaped, upper molar of *Centetes* (*plate 5, figs. A–D*).

As may be seen by comparing the upper molars of *Palæoryctes* with its premolars, it is also highly probable that the para- and metacones of the molars are homologous with the tips of the premolars, and with the apices of the molars, of Jurassic trituberculates, while its protocones, or basal internal cusps, appear to be outgrowths from the base of the crown, homologous with that of the fourth premolar.

Here, then, is an example of a fact observed in very many phyla of Paleocene and Eocene placental mammals, namely, that, *as we pass backward from the anterior premolars through the fourth premolar to the molars, the main tip of the premolar crown appears to be homologous with the paracone +metacone of the molars, while the internal basal spur of the premolars appears to be homologous with the so-called "protocones" of the molars.* It is highly unfortunate that this cardinal fact was long obscured by the unproved assumptions that the resemblance between p^4 and m^1 is largely secondary, and that the main tip of p^4 is homologous with the internal apex, or "protocone," of the first molar rather than with the paracone + metacone. This conclusion, now believed to be erroneous by nearly all investigators, arose from the circumstance that, according to the Cope-Osborn theory, the para- and metacones of the *upper*, as well as of the lower, molars had arisen, during the Mezozoic era, by the circumduction of the accessory cusps of an original triconodont tooth, although no upper molars were ever found in an intermediate stage of evolution.

So firmly was this hypothesis established in the literature, that the contradictory evidence afforded by the premolars of Eocene and later mammals was discarded, and a separate system of nomenclature was early invented by Scott for the cusps of the premolars, in which the name protocone was applied to the main apex of the upper premolars. Thus arose the anomaly that, in the lower premolar-molar series, the protoconids, or apices, of the trigonids were rightly regarded as homologous with the apices or protoconids of the premolars; so that, as we pass backward, the protoconids of the premolars and molars were arranged one behind the other in an anteroposterior series on the buccal side of the crowns; while in the upper dentition, according to the Cope-Osborn nomenclature, as we pass backward from the

premolars to the molars, the protocone suddenly shifts from the buccal side of the premolars to the lingual side of the molars! This inconsistency was challenged on embryological grounds by Röse, Kükenthal, Leche, Taeker, Marett-Tims and M. F. Woodward; while Winge, as far back as 1882, had held that the anterior external cone, or paracone, above, and the protoconid below, represent the "reptilian cone" both in the molars and premolars. This conclusion was also supported on palæontological and comparative anatomical grounds by Schlosser (1891) and Scott. Wortman (1903) and Gidley (1906) renewed the attack on this fundamental inconsistency of the Cope-Osborn theory. Wortman emphasized the insufficiency of the evidence for the "cusp-rotation" hypothesis and clearly formulated the "premolar analogy theory," the main point of which is that the evolution of the molars during pre-Tertiary times probably followed the same general lines as the observed evolution of the premolars in many phyla during the Tertiary.

Osborn (1907, pp. 216–217) was greatly impressed by the evidence against the Cope-Osborn view that the so-called "protocone" of the molars of primitive placental mammals represents the original reptilian cone and, in collaboration with the present writer, gave an impartial review of the whole problem. But he brought to the support of the original identification of the "protocone." or "anterointernal" molar cusp of later mammals, with the original apex of the crown, his later observations on the superior molars of the Upper Jurassic tritubercular *Dryolestes*. In this animal the internal apices of the upper molars have the appearance of being homologous with the so-called "protocones" of Tertiary mammals and Osborn took it for granted that they were so. But, as shown in Part I of this paper, a comparison of the upper teeth of *Dryolestes* and of *Kurtodon*, with those of their contemporary, *Peralestes*, affords convincing evidence that, in all three genera, the protocones or apices of the upper molars are serially homologous with the apex of the last upper premolar. Now, in *Palæoryctes*, *Didelphodus*, and many other Paleocene and later mammals, the apex of the last upper premolars is apparently the serial homologue of the paracone + metacone of the molars, not of the so-called "protocone." Hence it appears that the apices of the *Dryolestes* upper molars and premolars are not homologous with

the "protocones" of molars of later mammals but with the tips of their premolars, and with the para- and metacones.

On the inner side of these internal tips of the premolars and molars of *Dryolestes*, Osborn figured the beginnings of a basal cingulum (compare *plate 5E*). A similarly situated, but better developed, basal cingulum in later mammals may be traced from the premolars, where it gives rise to the so-called "deuterocone" or internal spur, backward to the "protocone" of the molars.

To return to *Palæoryctes:* (1) The lower molars of this animal have low and small talonids; and, in correlation with this fact, we find that the protocones or internal cusps of the upper molars, as well as the internal spur of the fourth premolar, are small and unexpanded, because the protocones of the upper molar fit into the basins of the talonids of the lower molars—and if one is small, the other must also be small. (2) The para- and metacones of *Palæoryctes* are small and closely appressed, one to the other, and located well toward the lingual side of the tooth. This is correlated with the small size, and especially with the narrow transverse diameter, of the hypoconid or posteroexternal cusp of the talonid, because, when this cusp is expanded transversely, as I have already shown, it pushes the para- and metacone apart, and tends to increase the anteroposterior diameter of the tooth. (3) The external cingulum and its cusps are well developed in *Palæoryctes*, and this is usually the case among mammals in which the para- and metacones are located well toward the lingual side of the crown. (4) The triangular interdental spaces of the upper molars are relatively large, because the primitive high trigonids fit solely into these interdental spaces and do not overlap on the crowns of the upper molars. All these characters, which recall the conditions in Jurassic trituberculates, may well be secondary in *Palæoryctes*, because this genus was evidently tending toward the modern zalambdodont insectivores, which are in many ways degenerate and specialized, and in which the para- and metacones become entirely confluent and widely displaced toward the lingual side of the crown, the internal ledges, or protocones, finally becoming vestigial, as shown by Leche, by Gidley (1906), and by Matthew (1913).

(5) All the elements of the *Palæorycytes* premolars and molars are evidently homologous with the more normal conditions retained in

Didelphodus, which, together with the primitive Oxyclænidæ, are far more central types.

The vast time-interval between the Paleocene *Palæoryctes* and the Jurassic trituberculates warns us against deriving the former directly from the latter; and the frequency with which similar dental patterns are brought about by convergent evolution, in widely different orders of mammals, inspires further caution. Nevertheless, *Palæoryctes*, *Didelphodus*, *Apternodus*, and various other early placental mammals, in which the paracones are more lingually placed and the external

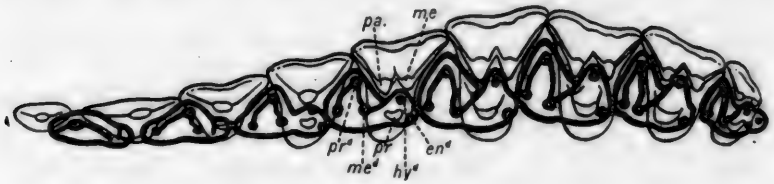


FIG. 44. DIAGRAM ILLUSTRATING (1) THE PROBABLE MODE OF ORIGIN OF THE MOLARIFORM PATTERNS OF PRIMITIVE PLACENTALS, AND (2) THE CORRELATED EVOLUTION OF UPPER AND LOWER TEETH

Successive stages are shown in passing from the simple anterior premolars, which have only the primary trigon, backward to the molars, in which the secondary trigon arises through the inward growth of the "protocones" and the division of the primitive apex into two cusps, the para- and the metacones. This hypothesis is based on indirect evidence and awaits direct palæontological confirmation, as the upper molars of the oldest known placental mammals of the Paleocene had already acquired the secondary trigon in the upper, and the expanded talonid of the lower, molars.

cingulum cusps are strongly developed, aid us in recognizing the following fact, which has never before been clearly formulated, namely, *that the homologue of the trigonid of the lower molars is not the so-called "trigon" of the upper molars, formed by the tips of the proto-, para-, and metacones, but it is the triangle formed by the tips of the paracone, parastyle and metastyle.* These original trigons of the upper molars alternate with the interdental spaces, which are filled in occlusion by the trigonids of the lower articulating molars, the apex of the primary trigon being on the lingual side while that of the trigonid is on the buccal side.

The secondary trigon, long confused with the primary trigon, later arose through the lingual growth of the internal basal cingulum, correlated with the overlapping of the lower molar talonid upon the inner side of the upper tooth. The primary trigon lost its triangular character through the separation of its para- and metacones, correlated with the transverse widening of the talonids, and the consequent development of large hypoconids, which wedge between the para- and metacones.

In the majority of placentals, the talonids rapidly increased in transverse diameter. This not only caused the anteroposterior separation of the para- and metacones, but often tended to push them toward the buccal side of the crown, as in many carnivores and primates, where the para- and metacones finally lie on the buccal side of the crown, and the external cingulum, primitively forming a large part of the outer side of the crown, becomes reduced or obsolete. *By these stages the primary trigon is almost completely effaced and a secondary trigon, consisting of the proto-, para-, and metacones, stands in its place.*

If this has been a universal rule, as I think it has, then many phyla of placental mammals were well advanced toward this stage when they first become known in the Paleocene and Eocene, but only the final stages of the transition, namely, the further development of the talonid, the separation of the para- and metacones, and the reduction of the external cingulum cusps, are actually known. This would explain the failure to recognize the differences between the primary trigon and the secondary trigon, which has given rise to so much confusion in the nomenclature. Meanwhile, the primary trigonids of the lower molars were often retained for the reason that they continued to wedge between successive upper molars, while a secondary or posterior trigonid, including the hypoconid, the crista obliqua, and the entoconid, was developed on the crown of the talonid.

The obliteration of the primary trigon, and the development of a secondary trigon and a secondary trigonid, is the opposite specialization from that in the zalambdodont insectivores, in which the para- and metacones are displaced toward the lingual side, while the talonids become reduced and the outer or stylar cusps become very conspicuous (see Matthew, 1913). Possibly, *Apternodus* Matthew of the Lower Oligocene,

and the existing *Chrysochloris*, represent a stage in which the primary trigon has been retained, while the secondary trigon has never progressed beyond the first stage, through the budding off of the basal internal cusp of the upper molars to give rise to the low protocones.

Origin of Omnivorous and Herbivorous Types of Molars in the Early Placentals

Up to this time we have been dealing, in the placental mammals, with teeth that were trigonal in form, whether exhibiting the primary trigon or the secondary trigon, or a combination of the two. In all such teeth, the interdental spaces between the upper molars are

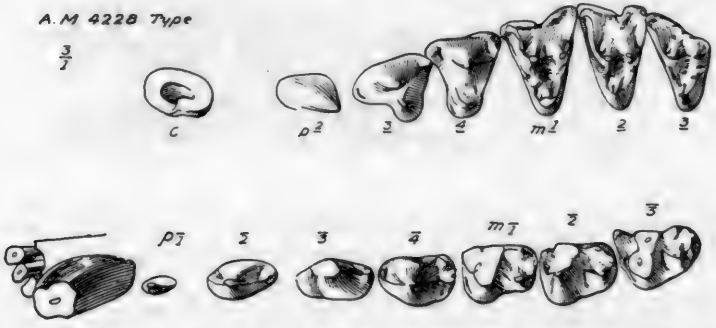


Fig. 45. Left Upper and Lower Teeth of a Primitive Insectivore, *Didelphodus absarokæ*, from the Lower Eocene of Wyoming. ×3/1
After Matthew. (Compare *fig. 47*)

The sharp blades of the trigonids of the lower molars shear past the blades of the uppers. The narrowness of the protocones, and the nearly central position of the para- and metacones, are correlated with the transverse narrowness of the talonids. See *fig. 47, A*.

conspicuous and receive the whole of the trigonids of the lower teeth. But, with the great expansion of the talonid, which in many lines had begun even before the Paleocene, there was a corresponding widening anteroposteriorly of the protocone; and, as we pass upward toward omnivorous and herbivorous types of later ages, there is a steady increase in the anteroposterior diameter of the whole tooth, correlated not only with the expansion of the protocones and talonids but also with the separation of the para- and metacones.

While the progressive overlapping of the talonids conditioned the development of the protocones of the upper molars, the later expansion of the trigonids, overlapping the posterointernal sides of the upper molars, conditioned the development of the hypocones, or posterointernal cusps. A similar development in the dentition of the marsupials has been described in Part I of this work. The typical hypocones of placental mammals arose as upgrowths from the posterointernal cingulum of the upper molars, which overlapped into the basins of the trigonids of the lower molars. As the hypocones develop the interdental spaces between the upper molars gradually become smaller and are finally crowded out.

FIG. 46. LEFT UPPER AND LOWER CHEEK-TEETH OF *Haploconus lineatus*, A PRIMITIVE PLACENTAL MAMMAL WITH TRITUBERCULAR UPPER MOLARS, FROM THE PALEOCENE OF NEW MEXICO. ×2. AFTER OSBORN

By the beginning of the Paleocene, the tritubercular molar type had been fully attained in most phyla of placental mammals; and was already undergoing diverse modifications tending toward the highly specialized molar patterns of later ages.

When this stage is attained, the trigonids no longer fit into the interdental spaces but they now articulate with the expanded surfaces of the upper molar crowns. The anteroexternal sides of the trigonids now shear past the expanded metaconules. The basins of the trigonids receive the hypocones of the upper molars, while the paraconids, if retained, very often articulate between the protocones and the hypocones. The posteroexternal slopes of the protoconids now shear past the anterior slopes of the protoconules, while the protoconids thus articulate between the paracone of one upper molar and the metacone of the next.

Since the old shearing and interlocking relations have now been largely superseded through the anteroposterior spreading of the upper molars,

new and diverse shearing adaptations are often developed by the elaboration of sharp crests on the surfaces of the crowns. These higher stages are attained in various ways, such as (1) by the emphasis of one or the other slopes of the proto- and metaconules; (2) by the subsequent

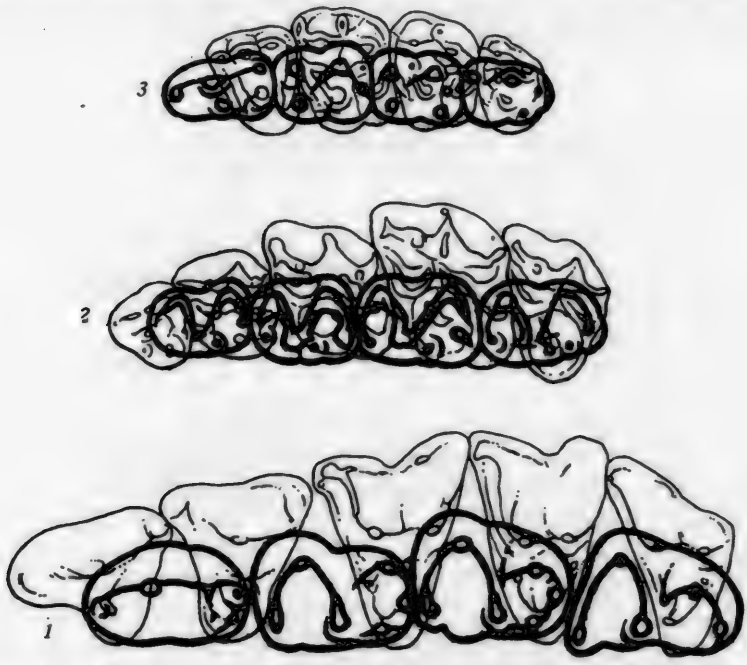


FIG. 47. OCCLUSAL RELATIONS OF THE UPPER AND LOWER CHEEK-TEETH IN EOCENE MAMMALS. (COMPARE *fig. 48*)

1.—*Didelphodus absarokæ*, a primitive insectivore with tuberculo-sectorial lower, and trigonal upper, molars. The interdental spaces are still widely open and the talonids are not expanded. ×6

2.—*Meniscotherium chamense*, an herbivorous mammal (Order Condylarthra) with relatively complex upper molar pattern. The paracone and metacone are V-shaped, and so is the protoconule; the metaconule bears an oblique straight crest; the hypocones are prominent, acuminate. The protocone is conical. In the lower molars the trigonid is V-shaped, with reduced paraconid, and the talonid-V is wide. Enlarged.

3.—*Phenacodus brachypternus*, a primitive condylarth with conical upper molar cusps and well developed hypocones. In the lower molars, the paraconid is absent and the principal cusps are arranged in two pairs which fit between corresponding pairs on the upper molars.

connection of these intermediate ridges with the four main cusps; (3) by the development of a large V or crescent on one or all of the cusps; (4) by the confluence of the para- and metacones into an ectoloph. Given the four main cusps, protocone, paracone, metacone, and hypocone, and the two intermediate cusps, the proto- and the metaconule, there is a wide range of possibilities in the manner in which these may

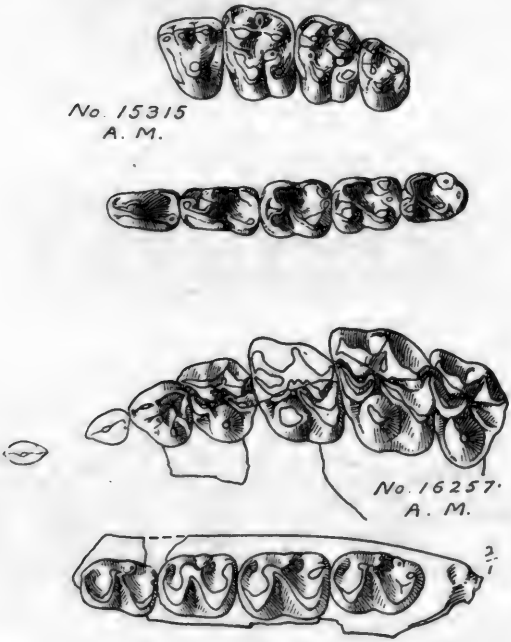


FIG. 48. LEFT UPPER AND LOWER MOLARS OF *Phenacodus brachypternus* AND *Meniscotherium Chamense*

be connected one with the other to form effective shearing and crushing relations with the homologous elements of the lower teeth. In the great series of ungulate orders, we find remarkably diverse developments of these possibilities, which have been set forth by Osborn and many others, and which afford diagnostic patterns of the molars in the multitudinous families of this group.

The underlying tritubercular pattern is obscured not only by these secondary complications, but is often more or less completely effaced as a result of the rapid vertical deepening of the crown and the further folding and twisting of its crests. This "hypsodont" transformation, which is very prevalent in the numerous families of ungulates and rodents, compensates for the rapid grinding down of the crown by silicious and woody material in the food.

II. INTRODUCTION TO THE STUDY OF THE EVOLUTION OF THE TEETH IN THE PRIMATES. DEPENDENCE OF ODONTOLOGY UPON PALAEONTOLOGY AND TAXONOMY, OR CLASSIFICATION ACCORDING TO KINSHIP

The lines of evolution of the molar patterns described above have not been discovered through an exclusive examination of the dentition. They are rather a by-product of innumerable studies, by palæontologists and systematists, on the anatomy and classification of recent and fossil mammals. Even studies on the chronological succession, geographic distribution and centers of dispersal of animals, and upon the palæogeographic histories of the countries in which they are found, have had an indirect bearing upon our knowledge of the evolution of the teeth of mammals, since such investigations, supplementing the morphological and taxonomic data, have brought to light many cases where more or less similar dental patterns have been produced at different times, in different places, and among widely different stocks. Accordingly, modern palæontologists are cautious about basing phylogenetic or evolutionary hypotheses on the evidence of similarities in teeth alone, unless the dental patterns compared be either very complicated or exceptionally peculiar and characteristic. It was formerly thought, for example, that the Eocene creodonts of North America were more or less intermediate between the carnivorous marsupials and the typical placental carnivores, but it is now recognized that quite similar adaptations to the shearing of flesh were independently produced at different times and in different places in all three groups.

It has not always been realized that, to be well-founded, theories of the evolution of the dentition must rest upon a broad palæontological and morphological base, and that the study of taxonomy, or classification ac-

cording to phyletic relationships, is the very cornerstone of such a base. For, without a full understanding of the taxonomic position and relationships of the organisms studied, it is easy to put too high a value upon random comparisons of structures in members of widely separated groups. *A considerable part of anatomical literature seems, indeed, to be filled with scattered comparisons of a few terminal and widely*

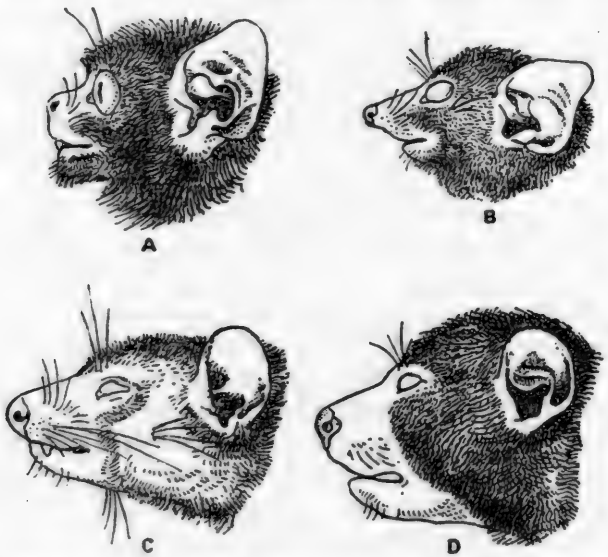


FIG. 49. HEADS OF *Tarsius* AND OF REPRESENTATIVE LEMUROIDS. ×¾. AFTER POCOCK. (DRAWN FROM SPIRIT SPECIMENS)

A.—Tarsius. Suborder Tarsioidea. Family Tarsiidæ. *B.—Hemigalago demidoffi.* Suborder Lemuroidea, Series Lorisiformes, Family Galagidæ. *C.—Chirogaleus major.* Suborder Lemuroidea, Series Lemuri formes, Family Lemuridæ, Sub-family Chirogaleinæ. *D.—Perodicticus.* Suborder Lemuroidea, Series Lorisiformes, Family Lorisidæ (Nycticebidæ).

separated twigs on different boughs and stems of the vast phylogenetic tree of the vertebrates. For example, the advocates of the concrescence theory, in its cruder form, point to the concrescence of teeth in the elasmobranchs in support of their view that mammalian molars have arisen through the concrescence of separate teeth, or of separate tooth germs, not realizing the tremendous taxonomic and chronological

gap between man and the elasmobranchs, or the fallacy of passing from one to the other without considering the intervening stages. Even at the present day there are those who point to chance cases of concrescence between adjacent teeth of modern mammals as evidence for the baseless hypothesis that mammalian molars originally arose in this manner millions of years ago in the prototherian ancestors of the mammals.

In considering the evolution of the human dentition we must constantly take into account the taxonomic relations of man to other primates. For the proper understanding of the subject it will naturally make a great difference whether man is an offshoot of the Old World series, whether he has been derived from some South American monkey, whether the human stem is remotely related to *Tarsius*, or is an entirely distinct family tracing its independent line back to the stem of the primates in pre-Tertiary times. It will therefore be worth while to summarize, briefly at this point, the history of the classification of the Primates in so far as it relates to the taxonomic position of man.

Even before the time of Linnæus various observers noted the marked structural similarities between man and the apes, which were especially evident in Tyson's classic studies on the anatomy of the chimpanzee (1699); but the doctrine of special creation had so firm a hold that it long inhibited recognition of the significance of such facts. One of the greatest discoveries of Linnæus was his clear, recognition that man is anatomically a member of the class Mammalia and that among all living animals his nearest relatives are the apes and monkeys. Therefore Linnæus, in 1759, grouped them with man under the order Primates, which he placed, in his Systema Naturæ, at the head of the animal kingdom. The recognition of this cardinal taxonomic fact prepared the way for the subsequent discovery that man had evolved out of some primitive primate stock.

As anatomical and taxonomic research progressed, it became evident to the majority of investigators that man belonged among the Old World series of primates, and that the surviving representatives of the order may be distributed as follows:

- Primates
  - Suborder Lemuroidea
    - Lemurs of Madagascar
    - Lorises, galagos, etc., of Asia and Africa
    - *Tarsius* of Borneo and other Malayan islands
  - Suborder Anthropoidea
    - Platyrrhinæ (New World monkeys)
      - Cebidæ: capuchins, howlers, etc.
      - Hapalidæ: marmosets
    - Catarrhinæ (Old World series)
      - Cercopithecidæ: monkeys of Asia and Africa
      - Simiidæ: anthropoid apes
      - Hominidæ: men

Recent researches by Pocock and others make it advisable to separate *Tarsius* and its allies from the lemurs, as a distinct suborder, Tarsioidea, combining features of the other two suborders. Wood-Jones, the prosector of the Zoological Society of London, will not admit that the lemurs are primates at all and regards man as a special branch from the stem of the Tarsioidea, thus removing him entirely from the suborder Anthropoidea. This proposed new alignment will be discussed below, and also more fully in other papers, but, for the purposes of the present article, the groups given above will be accepted as practically established through the long and world-wide process of research and criticism to which the problem of the relationship of man has been subjected.

III. THE LEMUROID PRIMATES (EOCENE TO RECENT)

Are the Lemurs True Primates or Pseudo-Primates?

Before taking up the palæontological history of the dentition of the Primates, it is necessary to consider briefly the relationships of the Lemuroidea to the remaining Primates and to other orders of mammals. Wood-Jones (1918, p. 26) is not willing to admit that the

lemurs are true primates at all, and therefore ascribes all their resemblances to the primates to a retention of primitive arboreal characters and to convergent evolution. If this were true, it would render nugatory the subsequent comparisons of the dentition of recent and fossil lemurs with those of the higher primates.

In a recent memoir (1920) on the American Eocene lemurs I have discussed the relations of the lemuroids to the higher primates and have concluded that the evidence is all against their proposed separation under a distinct order. It is true that the method of placentation in typical lemurs, so far as known, is radically different from that of *Tarsius* and the higher primates, and that every one of the modern lemurs has in many respects become specialized away from the primitive primate conditions. But most investigators have recognized that in the totality of their organization even the existing lemurs are at least the nearest relatives of the primates among all the orders of mammals.

The suborder Lemuroidea embraces a very wide range of forms. The more primitive Eocene lemuroids retain a number of primitive mammalian characters, especially in the skull and dentition, while the later and more advanced forms closely parallel the higher primates, so that the systematic position of some of them was once in doubt, on account of the very progressive and monkey-like appearance of their cranium and face. But, as shown by Forsyth Major and others, (1) it is now well established that these monkey-like lemurs (*Archæolemur*, *Nesopithecus*) are true lemuroids and in no sense transitional to the higher primates, and that their resemblances to the monkeys are an expression of parallel or homoplastic evolution. Nevertheless, this fact in itself considerably strengthens the claims of the Lemuroidea as a whole to be considered as true primates, *because it has frequently been observed by palæontologists that parallelism is more complete and detailed in nearly related than in widely removed stocks.* (2) Some of the recent and fossil Lorisidæ (Nycticebidæ) closely parallel the tarsioids in skull, dentition and limbs, so that formerly I had difficulty in deciding what characters are due merely to parallelism and what may indicate a closer relationship. The resemblances between some of the galagos and *Tarsius* are so numerous and detailed that, even after parallelism has been well discounted, a substantial agree-

ment in stem characters is surely indicated. (3) While some of the lemuroids appear to be remotely connected by numerous stem characters with the tarsioids, others, especially among the American Eocene forms, appear to be evolving toward the South American monkeys.

In brief, and without setting forth the full evidence in this place, it may be stated that *the right of the Lemuroidea to be included under the order of Primates seems much clearer at the present time than it was to Mivart and to Milne-Edwards.*

Origin of the Primates

From the Paleocene formations of the west no undoubted primates are known, although very possibly *Indrodon*, of the family Mixodectidæ, a genus with primitive molars but somewhat specialized procumbent incisors, may be related more remotely to the Primates and more closely to the Menotyphla. The latter group is represented at the present day by the Tupaiidæ, or tree-shrews, and the Macroscelidæ, or jumping shrews. The recent Tupaiidæ are more or less lemur-like in general appearance as well as in many anatomical and osteological details, so that they are probably the nearest living relatives of the pre-Tertiary ancestors of the Primates. Their feet and limbs are less specialized for arboricolous habits, but seem to be of sub-Primate type.

A second Paleocene and Eocene family, having claims to be included in the order of Primates, is the Plesiadapidæ, which, in the Tiffany formation at the summit of the Paleocene, is represented by *Nothodectes* (Fig. 54), a genus with enlarged and shrew-like front teeth, and with molars recalling those of *Pelycodus* and other Eocene primates. The skeleton of *Nothodectes* shows many significant resemb ances to the Tupaiid type, but is more primitive and at the same time recalls that of the Eocene lemuroids, especially the Notharctidæ. In the Lower Eocene of Europe a related genus, *Plesiadapis*, also has enlarged front teeth and primate-like molars, and is referred to the order Primates by Stehlin, the leading authority on the Eocene Primates of Europe. In 1910, I argued that the existing tree-shrews have preserved many intermediate conditions tending to connect the Primates

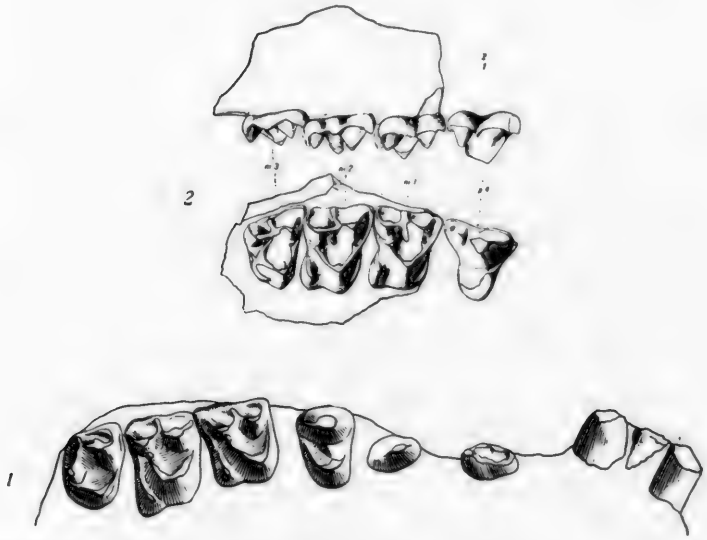


FIG. 50. A. TEETH OF POSSIBLE RELATIVES OF THE EXISTING TREE-SHREWS, FROM THE PALEOCENE OF NEW MEXICO. AFTER OSBORN

1.—*Indrodon malaris*. Amer. Mus., no. 3080. ×3.
2.—*Mixodectes* sp. Amer. Mus., no. 833. ×3.

FIG. 51. TEETH OF EXISTING TREE-SHREWS. ×3.

1.—*Tupaia*.
2.—*Ptilocercus*.

with unknown Mesozoic Insectivora of arboricolous habits. All recent evidence tends to confirm this view.

The American Eocene family of Hyopsodontidæ, which were formerly referred to the Primates and which resemble the Notharctidæ in many characters of the molars, have been removed from the order by Wortman; and were later shown, by Matthew, to belong with the

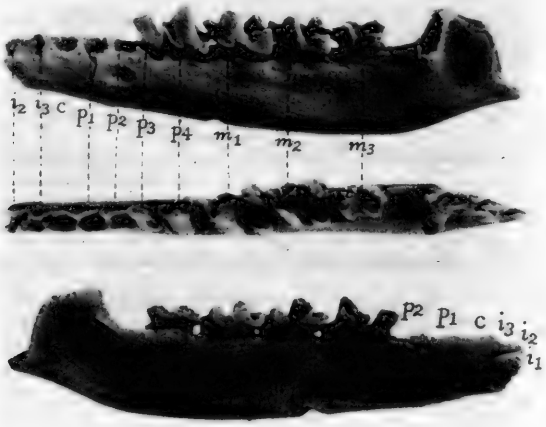


FIG. 52. LOWER JAW (LEFT SIDE) OF *Entomolestes grangeri*, A POSSIBLE RELATIVE OF THE TREE-SHREWS. AMER. MUS., NO. 11,485. MIDDLE EOCENE, WYOMING. ×6. AFTER MATTHEW

FIG. 53. SKULL AND MANDIBLE OF THE PEN-TAILED TREE-SHREW, *Ptilocercus lowii*. U. S. NAT. MUS., NO. 112,611. ×2

The skull and dentition present many points of resemblance to those of primitive primates.

Condylarthra, or primitive ungulates. Their resemblances to the Primates (*fig. 55*) afford a good example of the parallelism that is often developed in the dentition of animals that are shown by the construction of the limbs to belong in different but related orders.

FIG. 54. UPPER AND LOWER TEETH OF *Nothodectes gidleyi*, FROM THE TIFFANY FORMATION (SUMMIT OF PALEOCENE) OF COLORADO. ×3. AFTER MATTHEW. AMER. MUS., NOS. 17,171 (UPPER), 17,174 (LOWER)

An American representative of the extinct European family, Plesiadapidæ. As shown by the construction of the limbs, this animal is probably related to the tree-shrews and, more remotely, to the Primates.

The Primitive Lemuroids (Notharctidæ) of the American Eocene

Thanks chiefly to the intensive work of American Museum explorations under Granger, we can follow the evolution of the dentition of the Notharctidæ through a long series of ascending forms. The oldest members, from the base of the Lower Eocene, are very small, the lower molar series measuring only 11–14 mm. in length. As we pass upward, the size gradually increases until, at the summit of the Middle Eocene, *Notharctus crassus* is an animal about as large as a howler monkey and its lower molars measure 20–23 mm. in length.

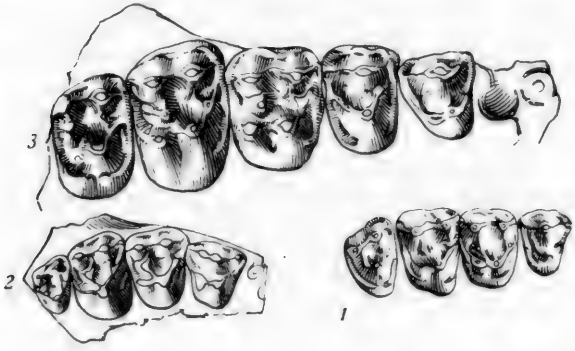


Fig. 55. Comparison of the Upper Molars of Primitive Primates (*1*) and Condylarths (*2, 3.*)

1.—Pelycodus trigonodus. After Matthew. ×2. *2.—Haplomylus speirianus.* After Matthew. ×2. *3.—Hyopsodus mentalis.* After Matthew. × 10/3.

Similarly, among the Eocene tarsioid series, the older and more primitive members are very small. There is, in brief, strong evidence for the view that the stem primates were quite small animals, even smaller then the existing tree-shrews, and of primitive insectivorous habits. That they were also arboricolous is shown by the relatively high degree of adaptations for such habits exhibited in the skeleton of their descendants, the Eocene primates. The skull in the older Lower Eocene species of the Notharctidæ is known from fragments which indicate that the orbits were relatively a little larger, and the zygomatic arches and temporal crests less well developed, than in the

later and larger species, especially *Notharctus crassus*. The skull of the Middle Eocene *Notharctus osborni* is shown in *fig. 56*.

The systematic position and relationships of the Notharctidæ are largely determined by the lemuroid characters of the skull and skeleton. The orbit, as in lemurs, was not separated from the temporal fossa by a bony partition but merely by a post-orbital process of the frontal, connected on the orbital rim with a similar upgrowing process of the malar. The whole construction of the skull closely resembles that of modern lemurs, with the important exception that the brain-case and the brain itself were much less expanded, and consequently more primitive and more like those of other Eocene mammals. Even

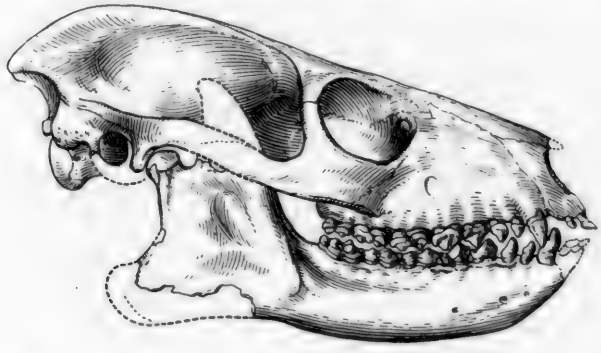


FIG. 56. SKULL AND LOWER JAW OF *Notharctus osborni*, A LEMUROID PRIMATE FROM THE MIDDLE EOCENE OF WYOMING. ×1. AMER. MUS., NO. 11,466

the minute characters of the bony cochlea, the bony canals for the internal carotid and stapedial arteries, the construction of the auditory bullæ and surrounding parts, and the form of the auditory ossicles, were all of lemuroid type. The same is true of the characters of the backbone, pectoral and pelvic girdles, and the limbs. The Notharctidæ, so far as our evidence goes, were confined to the New World and may well have given rise to the New World monkeys, as suggested by Leidy and by Wortman. But they are also rather closely related to the Adapidæ of the Eocene of Europe and may even be placed in the same family with them. The dental formula of the Notharctidæ ($I\frac{2}{2}$ $C\frac{1}{1}$ $P\frac{4}{4}$ $M\frac{3}{3}$) lacks but one incisor, on each side

FIG. 57. UNDER SIDE OF THE SKULL SHOWN IN FIG. 56. ×2

above and below, of the formula of the stem placental mammals ($I\frac{3}{3}$ $C\frac{1}{1}$ $P\frac{4}{4}$ $M\frac{3}{3}$), and all the teeth are in a very primitive and characteristic Lower Eocene stage of evolution. The upper and lower dental arches are also very primitive. The lower incisors and canines totally lack the specialization seen in modern lemurs, by which all the incisors become transformed into small, procumbent, or porrect, compressed teeth, the lower canines are taken over into the incisor

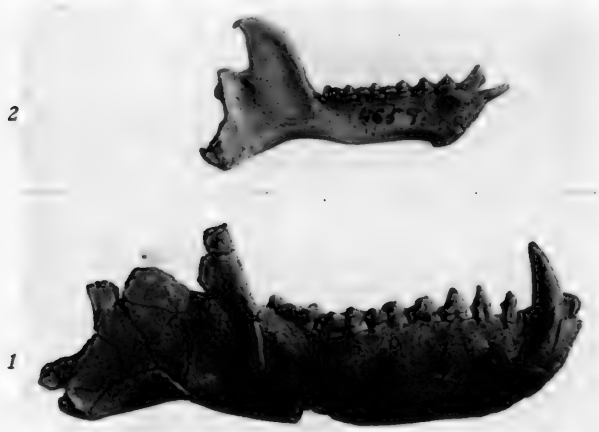


FIG. 58. LOWER JAW (RIGHT RAMUS) OF (1) AN EOCENE LEMUROID *Notharctus venticolus* (AMER. MUS., NO. 14,655) AND OF (2) A MODERN LEMUR, *Lepilemur mustelinus* (AMER. MUS., NO. 4,659). NATURAL SIZE

In the ancient lemuroid the incisors (here represented by their alveoli), canines and four premolars, are primitive, both in form and in position; but, in the modern lemur, the front teeth are specialized, the incisors and canines being much alike, reduced in size and directed sharply forward. The prominent projecting tooth, in the front end of the tooth row, represents the second lower premolar of more primitive mammals, the first having been lost.

series, and the second lower premolar is modified into an erect, almost caniniform, tooth. In the Eocene Notharctidæ, on the contrary, the lower incisors and canines were not notably different from those of other primitive mammals. Partly because the lower incisors and canines of the Notharctidæ had not assumed the lemurine specialization, the family has been excluded, by Wortman, from the Lemuroidea; but, as fully shown elsewhere (*Memoirs of the American Museum of*

Natural History, 1920), the characters of the dentition, skull, and skeleton are unquestionably lemuroid.

The lateral upper incisors were already beginning to assume somewhat the compressed shape which is retained in certain modern lemurs (*Chirogaleus*). Stehlin (1916, p. 1530) argues that the canines of the original primates must have been small and more or less intermediate between the incisors and the premolars. But in all known Palæozoic, Mesozoic, Paleocene, and Eocene orders, except the multituberculates, the canines are usually more or less enlarged, and well differentiated both from the incisors and the premolars. Stehlin boldly meets this difficulty by assuming that such cases are already specialized away from the hypothetical condition conceived by him to be primitive, but I prefer not to set aside so lightly the direct palæontological and comparative anatomical evidence.

In brief, these primitive Lower Eocene lemuroids indicate *that in the stem primates the canines were well differentiated from both the incisors and the premolars, and that the lower canines occluded in front of the upper with their tips directed slightly outward.* Very probably in a premammalian stage of evolution the lower canines had occluded inside of the uppers and their tips were received in sockets in the upper jaw, as may be observed in the cynodont reptiles. But even in the oldest mammals the tips of the lower canines had become directed slightly outward, so that they occluded chiefly in front of the uppers, with their tips pointing buccally. This condition is preserved in a great majority of the primates; and it is only in the lemurs on the one hand, and in man, on the other, that the canines, as a result of reduction, come to occupy entirely new and anomalous positions.

The evolution of the premolar series in the Notharctidæ, as shown in the species from ascending levels, parallels that in many other Eocene phyla of placental mammals and lends further support to the "premolar analogy theory" of the origin of the tritubercular molar. First, as we pass backward, from the simple pointed tip of the first lower premolar (p_1) to the submolariform crown of p_4, there can be no doubt that the real protoconid, or original tip, is on the buccal side of the crown; but in the upper molars, if we were to accept the Cope-Osborn view, we should have to pass suddenly from the buccal tip of p^4 to the lingual tip of m^1. Secondly, the lower premolars show also the most detailed

steps in the evolution of a submolariform pattern, starting with the simple, compressed, protoconid of the first premolars. The posterior slope of the first lower premolar, and still more that of the second premolar, shows faintly the very beginnings of a talonid, which becomes larger and more distinctly modelled as we pass backward towards the third and fourth premolars. The third lower premolar of the later species shows also the incipient separation of the paraconid and metaconid from the anterior and posterior slopes, respectively, of the protoconid. The lower molars also illustrate the progressive development of the trigonid, which becomes subtriangular in p_4 and fits into the interdental space between the third and fourth upper premolars. *In this progressive modelling of the lower premolars, the internal cingulum plays a prominent part, since it gives rise to the incipient paraconid, to the basin of the talonid, and to the incipient hypoconid* (*plate 6*).

In correlation with these changes in the lower premolars, the upper premolars also gradually attain a submolariform type, both as we pass backward from the compressed tip of p^1 and as we follow the course of evolution in successive species. In the more anterior upper premolars, the apices bite outside of the protoconids of the lower teeth. The internal ledges, which are progressively developed on $p^2 - p^4$, at first engage with the progressively developed talonids of the lower premolars. In the older members, even the fourth upper premolar has only a single external apex; but, with the progressive widening of the talonids and the buccal growth of the hypoconids, the single apex gradually divides into two, so that in the latest stage there are two cusps on the outer side of p^4. These, however, are still close together because the hypoconid of the lower premolars never becomes as large as that of the molars. Also, the anteroposterior diameter of p^4 is much less than that of the molars because the anteroposterior diameter of p_4 is also relatively small (*plate 7*).

The upper premolars of the earlier forms have a very distinct external cingulum, representing the reduced outer part of the primitive upper premolar crown. In the premolars of the later members of the series, this external cingulum, although somewhat less pronounced, is still evident. On the posterior premolars of the earlier stages there are small stylar cusps, corresponding to the parastyle and metastyle.

FIG. 59. RIGHT UPPER CHEEK-TEETH OF *Notharctus osborni*, A LEMUROID FROM THE MIDDLE EOCENE OF WYOMING. AMER. MUS., NO. 11,466. ×3.

The first upper premolar is represented by its alveolus; the second has a simple compressed crown which, however, shows the beginning of structures which attain a fuller development in the third and fourth premolars.

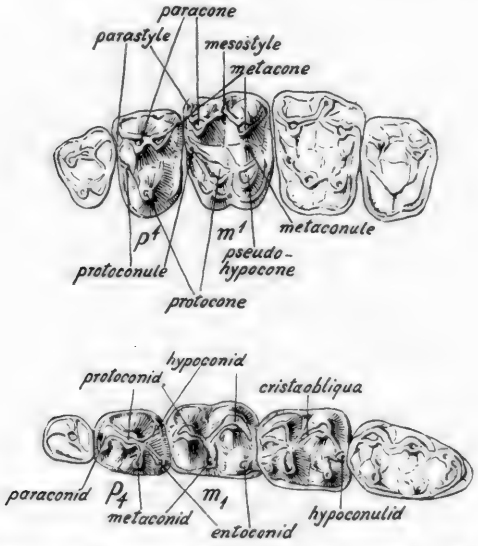


FIG. 60. UPPER AND LOWER CHEEK-TEETH OF *Notharctus crassus*, AN EOCENE LEMUROID

Illustrating the names of the principal cusps, etc., of the premolar and molar crowns. Osborn's names for the parts of the molars are used also for the similarly placed parts of the premolars.

FIG. 61. UPPER AND LOWER TEETH, IN OCCLUSION, OF (1) *Pelycodus trigonodus* (AMER. MUS., NO. 15017, LOWER EOCENE, WYOMING) AND (2) *Notharctus crassus*, (AMER. MUS., NO. 11,982, MIDDLE EOCENE, WYOMING). ×3. (INNER SIDE)

In the older and more primitive species, *Pelycodus trigonodus*, the pseudo-hypocones, or postero-internal cusps of the upper molars, are but poorly developed; thus, the interdental spaces are not restricted and receive the greater part of the trigonids of the lower teeth. In the later species, *Notharctus crassus*, the pseudo-hypocones are fully developed, encroaching on the interdental spaces and articulating with the paraconids of the lower molars.

These retain their distinctness in the later members. They did not articulate with any part of the lower teeth, but assisted in pressing the food against the lower teeth and in increasing the hold of the teeth upon the food.

The inner side of the upper premolars terminates in the low apex, apparently homologous with the socalled "protocone" of the molars; it arose, as already stated, in correlation with the expansion of the talonids of the lower molars. At first, this internal spur lacks all trace of a posterointernal division; but, in the fourth upper premolar of the latest stage, there is an incipient cusp which is beginning to separate from the posterior slope of the internal spur of p^4. This low postero-internal cusp, called the tetartocone in Scott's nomenclature, articulates with the paraconid of the first lower molar.

Thus, both on the outer and on the inner side of the crown, the fourth upper premolar of the Notharctidæ exhibits an incipient tendency to divide into anterior and posterior moieties; in other words, to assume the molariform pattern which is more fully realized in the last deciduous premolar. In this respect the posterior upper and lower premolars thus parallel the conditions in many other Eocene phyla, but in this series the transformation is slower and less complete; and in many of the higher primates the posterior premolars are less molariform than in the later species of Notharctidæ.[4]

The difference in pattern in p^4 and p^3 in the Notharctidæ is always pronounced, while in many other primates p^4 and p^3 become very much alike. Here again the Notharctidæ are more like other phyla of Eocene mammals, and the conditions of the premolars in the higher primates are in all probability less primitive, although more simple in appearance.

The first and second lower molars of the earliest Notharctidæ have all the elements of the primitive tuberculo-sectorial tooth; that is, the trigonid bears all three primitive cusps, and the talonid already has a high hypoconid and a low entoconid. Moreover, the trigonid is on a considerably higher level than that of the talonid, while the hypoconid is connected with the posterior wall of the trigonid by a prominent "crista obliqua." Thus, the lower molar is surmounted by

[4] By this I mean that the relative simplicity of the bicuspid premolars of later primates may be due to arrest of the tendency to become molariform and to divergence in function of premolars and molars.

two Vs—the smaller V, formed by the cusps of the trigonid; the much wider posterior V, formed by the crista obliqua, the hypoconid and the entoconid (*fig. 62*). Such a pattern is seen in many other Eocene phyla.

As we pass upward from the lower and more primitive species of Notharctidæ, the paraconids of the lower molars disappear or are retained only in a reduced condition Meanwhile, the crest connecting the protoconid with the metaconid assumes a more anterior posi-

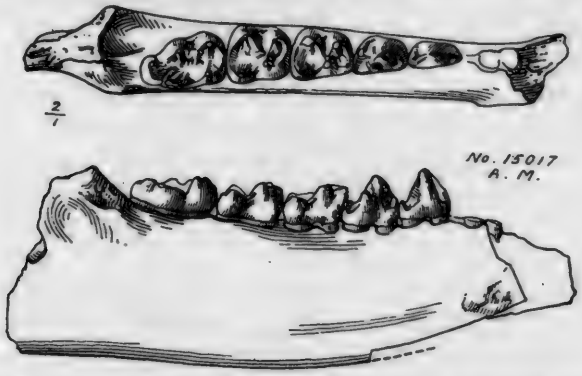


FIG. 62. LEFT MANDIBULAR RAMUS OF *Pelycodus trigonodus*, A PRIMITIVE NOTHARCTID FROM THE LOWER EOCENE OF WYOMING. AMER. MUS., NO. 15,017. ×2. AFTER MATTHEW

In the fourth lower premolar, the trigonid and talonid of the molars are foreshadowed, but the third lower premolar retains its simple conical shape, with only an incipient paraconid and a very small talonid. In the molars, the trigonid is still on a higher level than the talonid—the paraconid, especially on m_1, is retained; the talonid of m_1,m_2 has already surpassed the trigonid in width.

tion, while the whole talonid and its V-shaped hypoconid become larger. At the same time, the trigonid becomes relatively lower and the talonid higher, so that the general level of the talonid is only a little below that of the trigonid. *This expansion of the whole talonid, including the hypoconid, as in so many other cases, is associated with the reduction of the interdental spaces between the upper molars, with the lengthening of the anteroposterior diameter of both upper and lower molars, with the further increase of the protocones which fit into the talonids; finally, with the progressive separation of the para- and meta-*

styles, and with the filling out of the postero-internal corner of the tooth, so that the hypocones occupy much of the space formerly filled by the trigonids of the lower molars (*fig. 61*).

In most phyla of mammals the true hypocones, or postero-internal cusps of the upper molars, arise as upgrowths of the cingulum, and progressively articulate with the basins of the trigonids of the lower molars. In the Notharctidæ, on the other hand, the postero-internal cusps arise as a budding or outgrowth from the posterior slope of the protocones, and they articulate rather with the paraconids of the lower molars. In the lower, older species of the family (*plate 7*), this process is just beginning on the first and second molars, and has not yet begun on the third molar. In later members this cusp becomes larger and larger, until, in the first upper molar of the highly progressive *Notharctus crassus*, the postero-internal cusp is even larger than the protocone itself. All the while the internal cingulum, which in other mammals gives rise to the hypocone, remains distinct and fails to produce a normal hypocone. *The budding off of the postero-internal cusp or pseudohypocone in the Notharctidæ has probably been conditioned by the attrition of the upgrowing entoconid of the lower molar.* When the mandible is moved obliquely, this cusp shears transversely across the posterior slope of the protocone just in front of the pseudohypocone; the latter also articulates directly with the paraconid of the next lower molar. In the titanotheres and other perissodactyls, a somewhat similar process in the premolars conditions the origin of the so-called tetartocone, which buds off from the posterior slope of the main internal cusp immediately behind the place where that cusp is worn by the upgrowing entoconid of the lower molar. The same process occurs also in the Equidæ and other perissodactyls.

In correlation with the more rapid development of the postero-internal cusp of the first upper molar of the Notharctidæ, we find that the level of the talonid of the first molar is higher than that of the second molar. The former tooth is also more conservative in the retention of the paraconid, which tends toward reduction or disappearance in the second and third molars of later species. When present, the paraconid articulates with the pseudohypocone of the preceding upper molar (*figs. 61, 63*).

The progressive development of a mesostyle on the upper molars is another specialization in which the Notharctidæ parallel many

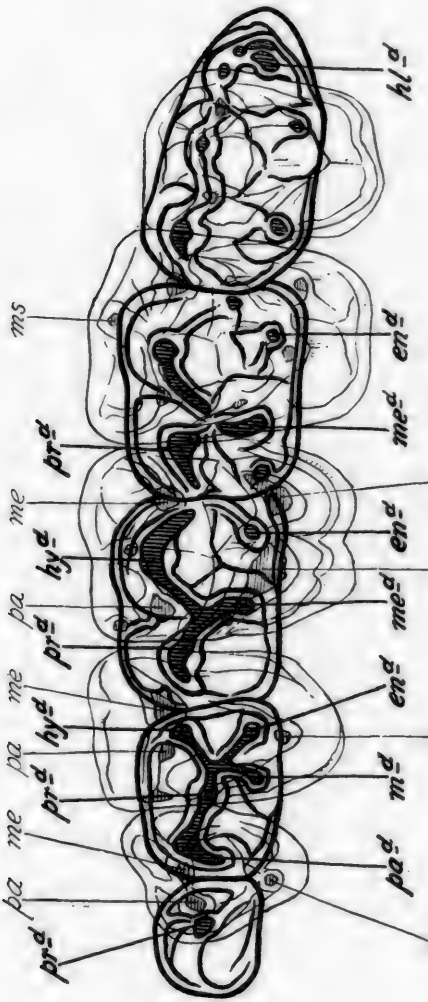


FIG. 63. PROJECTION OF THE LOWER UPON THE UPPER CHEEK-TEETH OF *Notharctus crassus*

Illustrating the articular relations of the upper and lower teeth when the mandible has been shifted toward the outer side. The protoconids of the lower teeth fit between two upper teeth.

other phyla of Eocene and later mammals. In the earlier members of the family, the mesostyle is barely indicated by a very slight wrinkle in the external cingulum between the para- and metacones. This steadily becomes larger, culminating in the robust mesostyle of *Notharctus crassus*. *As in so many other cases, these cusps do not articulate with the lower teeth, except when the lower jaw is swung far to one side so as to bring the hypoconids opposite the mesostyles, but they assist chiefly in pressing the food against the lower molars.* The mesostyle is connected with the slopes of the para- and metacones and, finally, coöperates with them in the formation of two well developed external Vs, or crescents, on the outer side of the tooth. These two Vs open outward, while the Vs of the lower molars open inward, a device frequently adopted among herbivorous dentitions and apparently efficient in the subdivision of a vegetable or mixed diet.

The third molars, both in the upper and lower jaw of the Notharctidæ, are narrower transversely, and in all respects less progressive, than the second molars. The third upper molars fail to develop a pseudo-hypocone, or postero-internal cusp, and the mesostyle is also smaller than in m^2. The third lower molar, even in the oldest forms, has a hypoconulid, or median posterior spur, which articulates just behind the posterior border of the third upper molar, and assists in a pivoting action when the jaw swings from side to side.

As shown by a careful study of the articulating relations of the upper and lower teeth in various species of Notharctidæ, and also by the mandibular condyles and glenoid fossæ, the lower jaw in the earlier forms had a somewhat more vertical movement, while in the later forms with crescentic molars there was a considerable transverse swing of the mandible (*fig. 67*). This ruminant-like action of the lower jaw is developed also in the howler monkeys of the New World series, and in *Propithecus* among the indrisine lemurs of Madagascar. *Probably the increasingly transverse component of the movement of the lower jaw conditioned, or was associated with, the development of both the pseudo-hypocones and the mesostyles in the upper molars, since the entoconids of the lower teeth sweep across the isthmus connecting the two internal cusps of the upper molars, while the hypoconids sweep across the region from the inner side of the mesostyle to the inner side of the protoconule.*

The deciduous dentition of *Notharctus* agrees with that of the European *Adapis* in the fact that all the molars erupt early, while the deciduous teeth are still in use. This is also the condition in the modern lemurs. In the higher primates, on the contrary, the eruption of the second and third molars is delayed until the close of the replacement period. As in many other mammalian phyla, the last

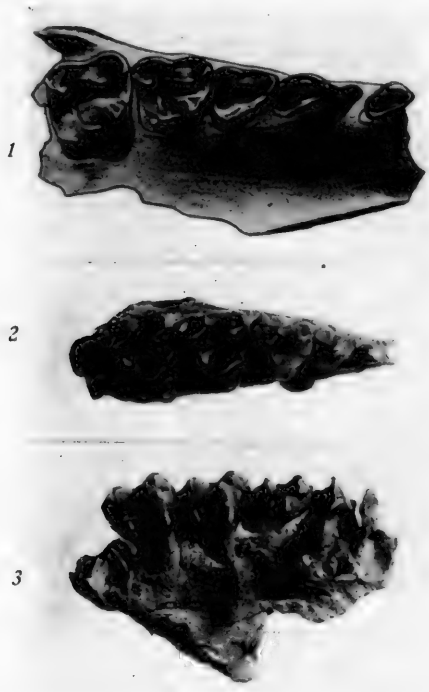


FIG. 64. DECIDUOUS AND PERMANENT UPPER TEETH OF *Adapis magnus* AND *Notharctus tyrannus*

1.—*Adapis magnus*. Eocene of Europe. ×2. After Stehlin. From left to right the teeth in place are m^1, dp^4, dp^3, dp^2, alveolus of p^1, dc.

2, 3.—*Notharctus tyrannus*. Amer. Mus., no. 13,025; Middle Eocene of America. ×2. The third molar has barely begun to erupt; m^2, m^1 and three deciduous premolars are in place, with the permanent p^4, p^3, and space for p^2 beneath them. As in most other mammals, the posterior deciduous teeth are more molariform than the permanent teeth that succeed them. In these Eocene lemurs the true molars are in use along with the deciduous teeth.

deciduous premolars are molariform in general pattern, while their successors, the fourth premolars, are much simpler.

We may summarize the morphology and evolution of the dentition of the Notharctidæ as follows:

(1) Dental formula: the primitive one for Primates; differs from the primitive placental formula only in the loss of one incisor on each side above and below. Same formula retained in the Adapidæ, but variously reduced in later primates.

(2) Dentition: increases in size from the Lower, through the Middle, Eocene; the length of the three lower molars rises from 11 to 23 mm.

FIG. 65. LOWER JAWS OF *Notharctus tyrannus*. AMER. MUS., NOS. 13,029 AND 12,578. ×2

All the true molars were in place before the deciduous molars were shed.

(3) Lower incisors and canines: of primitive placental type; not specialized as in lemurs, but not very different from those of the more primitive South American monkeys.

(4) Evolution of the premolar series: parallels that in other Eocene placental mammals and lends support to the "premolar analogy" theory of the origin of the tritubercular molar.

(5) Evolution of the upper molars: from the trigonal to the quadrangular type, with consequent reduction of the interdental spaces

correlated with an increase in the anteroposterior diameter of the crowns, and with the expansion of both the protocones and the talonids that receive them.

(6) Budding off of the postero-internal cusps, or pseudo-hypocones from the posterior slopes of the protocone: conditioned by, or associated with, the attrition of the entoconids of the lower molars; the pseudo-hypocones articulate with the reduced paraconids.

(7) Progressive development of mesostyles on upper molars: correlated with obliquely transverse movements of the mandible in mastication.

The Adapidæ of the Eocene of Europe

These European relatives of the Notharctidæ resemble the latter in so many fundamental characters of the dentition, skull and limbs, that they may well be united with them in a single family, for which the prior name, Adapidæ, has often been used. But the American and European representatives of this group are, on the other hand, separated by a number of minor but trenchant differences, which make it desirable to class them as either distinct families, as Stehlin does; or, at least, as very distinct subfamilies, Notharctinæ, Adapinæ, as I have done in the memoir already cited. Stehlin has emphasized the fact that, in the American family (or subfamily), the so-called hypocones, or postero-internal cusps, of the upper molars are really pseudo-hypocones, formed by budding off from the antero-internal cusps or protocones; while, in the European series, the hypocones are formed by the upgrowth of the postero-internal cingulum in the more usual mammalian fashion. He also noted that, in the Notharctidæ, the upper molars develop mesostyles, which are entirely absent in the Adapidæ. But I have shown (1920) that, although these and other differences demonstrate a divergence in evolutionary trend, they do not disprove a common origin of the two groups, as evidenced by the long list of primitive lemuroid characters which they have in common.

The differences in the molars noted above are associated with corresponding differences in the normal paths of the mandibular excursion during mastication. In the Notharctidæ, as already noted, the

excursion of the mandible became increasingly lateral, so that the lower grinding teeth were swept part way across the crowns of the upper teeth, and the incipient mesostyles pressed the food against the hypoconids; while the pseudo-hypoconids grew out just behind

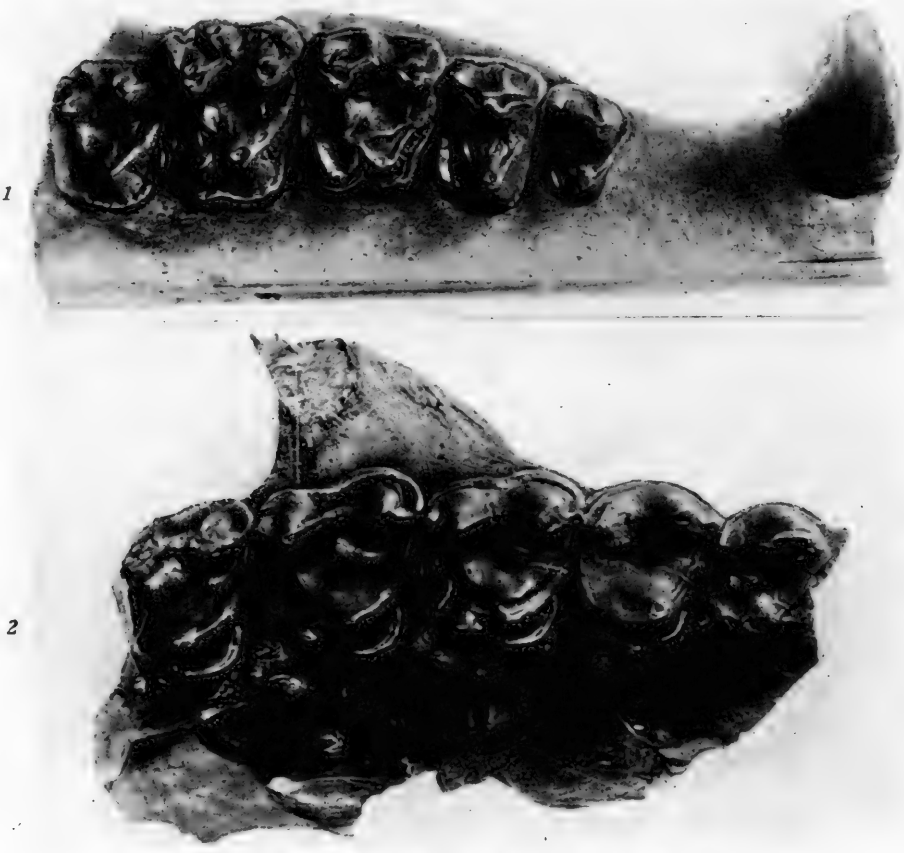


FIG. 66. UPPER CHEEK-TEETH OF *Notharctus* AND *Adapis*

1.—*Notharctus crassus*. Amer. Mus., no. 11,982; Middle Eocene, Wyoming. ×3.
2.—*Adapis magnus*. Amer. Mus., no. 10,511; Eocene, France. ×3.
Shows, in *Notharctus*, the presence of mesostyles and of pseudohypocones; in *Adapis*, the absence of mesostyles and the presence of true hypocones, connected with the internal cingulum.

the points where the entoconids swept across the posterior ridge of the protocones, and also came into contact with the reduced paraconids of the lower molars. In the Adapidæ, on the other hand, the excursion of the mandible remained more vertical, no mesostyles were developed and the true hypocones finally came to articulate with the basin of the trigonids, as in many carnivorous mammals,

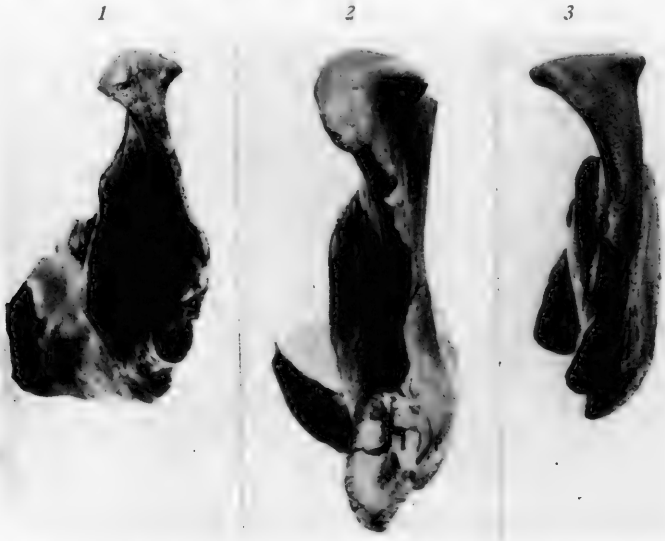


FIG. 67. REGION OF THE MANDIBULAR CONDYLE OF *Notharctus* AND OF *Adapis*. VIEWED FROM THE REAR. ×2

1.—*Notharctus osborni*. Amer. Mus., no. 11,466.
2.—*Notharctus crassus*. Amer. Mus., no. 12,588.
3.—*Adapis parisiensis*. Amer. Mus., no. 10,007.

The more convex condyles of *Notharctus* permitted freer movements of the mandible, while the flatter and more transversely extended condyle of *Adapis* implies a more orthal (vertical) movement.

with a chiefly vertical excursion of the mandible. So also, in association with the vertical movement, the protoconule crest of the Adapidæ became well developed (*fig. 66*), foreshadowing the conditions in the modern Lemuridæ (*fig. 70*). These differences in the excursion of the mandible are associated with corresponding differences in the mandib-

ular condyles, those of *Notharctus* being rounder and permitting freer movements; those of *Adapis* being flatter and suggestive of the condyles of carnivores (*fig. 67*).

FIG. 68. SKULL AND LOWER JAW OF *Adapis magnus*. × 1. AFTER GRANDIDIER

The skull in general resembles that of the larger species of *Notharctus*, but is distinguished by the heavier jaw and stouter zygomatic arch. The orbit, as in other lemuroids, opens beneath the postorbital bar into the temporal fossa.

Setting aside the differences in the dentition noted above, the whole construction of the skull in the Adapidæ, including the detailed characters of the bony face, brain case, auditory region, etc., on the one hand represents an advance upon the conditions exhibited in the Notharctidæ; on the other hand foreshadows the Lemuridæ.

Origin of the Lemuridæ

Forsyth Major, after extensive comparisons of the auditory and lacrymal regions of the skulls of primates, came to the conclusion that the modern Lemuridæ had been derived from the Adapidæ. This is the view I have endeavored to defend in the memoir cited above. But Stehlin, the leading authority on the Eocene primates of Europe, would exclude at least the typical Adapidæ from such a connection, on the ground that they are already too specialized in certain characters of the dentition and of the skull to be ancestral to the Lemuridæ. I have argued, on the contrary, that *it is of the greatest importance to realize that Eocene ancestors may be expected to resemble or foreshadow their modern descendants only in respect of those characters the function of which has either remained the same or has become intensified in a positive sense; and that, on the other hand, the Eocene ancestors will differ from their descendants in proportion as their adaptive characters have suffered a radical change of function.* Accordingly, I have endeavored to show that the chief differences in the dentition and skull between *Adapis* and the Lemuridæ (which have been cited by Stehlin as excluding the former from ancestry to the latter), may rather be interpreted as signs either of changes of function and structure or, in some cases, of marked intensification of function of the given parts.

In the most primitive Adapidæ the dentition (*fig. 71*) approaches the normal primitive form exhibited in other placental orders. Consequently the aberrant specialization of the incisors, canines, and anterior premolars, which is characteristic of the Lemuridæ and other lemuroid families, is surely a later acquisition, and the lack of it in the Eocene Adapidæ by no means excludes that family from ancestry to the Lemuridæ. In modern lemurs the specialization in question is connected with the habit of combing and cleaning the fur with the lower front teeth, and is associated with a thickening and enlargement of the tongue, as well as of the sublingua, so that the minute and procumbent lower incisors, and canines, fit beneath the overlapping and more or less protrusile tongue. This peculiar modification in the several families of modern lemuroids has very probably been acquired independently, starting from the more primitive conditions illustrated in *Adapis priscus* and the more primitive Notharctidæ.

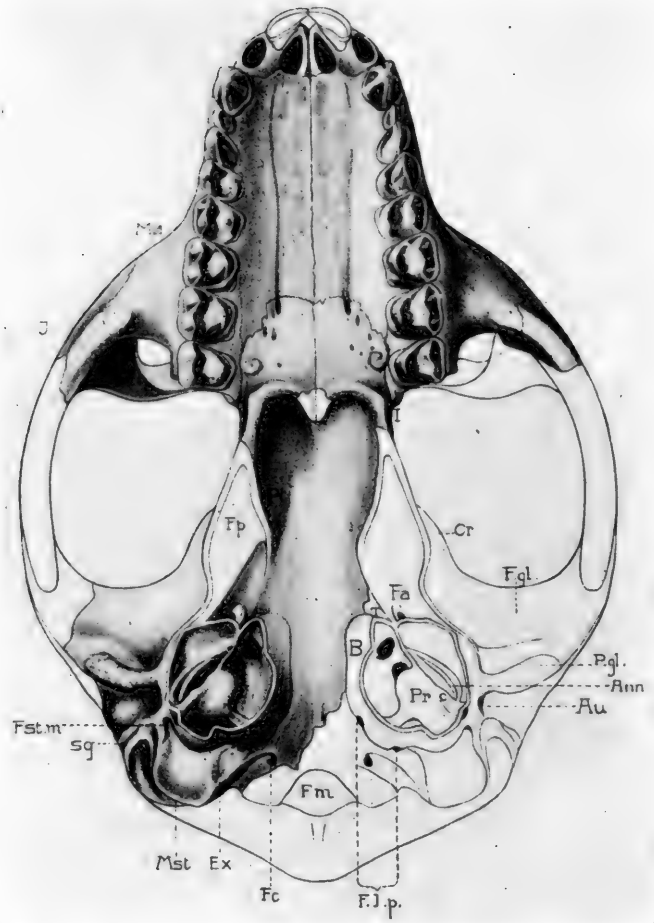


FIG. 69. UNDER SIDE OF THE SKULL OF *Adapis magnus*. ×1. AFTER STEHLIN

In the construction of the auditory region and many other parts, the European Adapidæ are closely related to the American Notharctidæ. In another direction they foreshadow the modern Lemuridæ in skull and dentition.

FIG. 70. UNDER SIDE OF THE SKULL OF A RECENT LEMUR, *Lepilemur mustelinus*. ×2

Shows numerous points of resemblance to *Adapis*, but differs in the more specialized form of the front teeth.

Here we have an excellent example of the phenomenon *that numerous similar specializations are often independently developed in families that have been derived from a common stock.* The opposite principle, that *wide differences may also be evolved in closely related stocks,* is well illustrated by the wide adaptive radiation of the molar patterns in the various families of Lemuroidea.

FIG. 71. LEFT MANDIBULAR RAMUS OF *Adapis sciureus.* ×4. AFTER STEHLIN. LOWER EOCENE, EUROPE

Shows the relatively primitive form of the teeth and the primitive dental formula: $I_2\ C_1\ P_4\ M_3$. The molars, however, have lost the paraconids and have wide talonids.

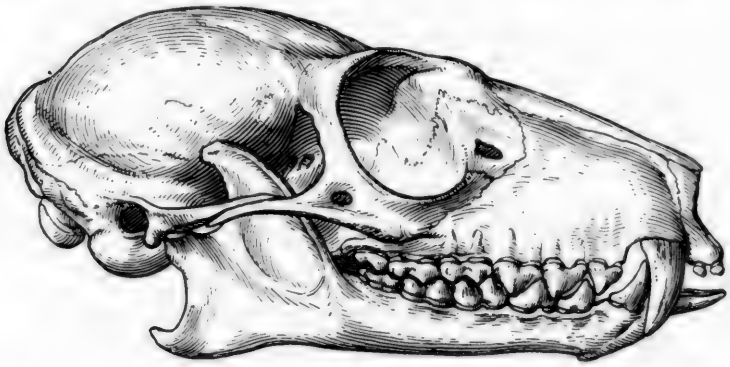


FIG. 72. SIDE VIEW OF THE SKULL OF A MODERN LEMUR (*Lemur varius*). ×1

Shows particularly the specialized character of the lower front teeth, the enlargement and subcaniniform shape of the anterior lower premolar, the lengthening of the lower jaw, and the expansion of the lacrymal bone and brain-case.

Adaptive Radiation of the Dentition in the Higher Lemurs of Madagascar. "Habitus" and "Heritage"

There can be no reasonable doubt that the Archæolemuridæ, an extinct family of Madagascar lemurs, were true lemuroids; and yet, in some of them, the upper molar teeth became bilophodont, so as to suggest at first sight the bilophodont molars of the Cercopithecidæ. The same genera also acquired a short face and expanded brain-case so that they were erroneously regarded by some as transitional between monkeys and lemurs. But their true status as lemurs is revealed by the retention of many highly significant lemuroid features in the skull and skeleton.

More recently acquired characters and special adaptations to the final life habits constitute what I call the "habitus," or adaptive form of the animal, while characters which it has inherited from ancestors in an earlier stage of evolution, and before the assumption of its present life habits, make up its "heritage." Both sets of characters are adaptive, but the first set are adapted to its present life habits; and the second set were adapted to the different life habits of its ancestors, and have been retained either because they are still useful, or because they have not yet been eliminated by later adaptations. This cardinal principle is of the utmost importance in the study of the evolution of the human dentition and of the whole question of man's relationship with other primates.

While the Archæolemuridæ tend to evolve bilophodont molars, *Propithecus* of the Indrisidæ has selenodont molars, that is, the molar patterns consist of Vs or crescents, which recall the conditions in the Eocene Notharctidæ but are more specialized. In *Indris* itself, the crescentic pattern of the upper molars is more or less effaced, the cusps losing much of their crescentic shape and the crowns tending to be divided into subequal anterior and posterior moieties.

The Indrisidæ also afford an instructive example of the reduction in the number of premolars from four to two, a reduction which has occurred independently in many other groups of primates. Even in the Notharctidæ, the first and second premolars, both in the upper and lower jaw, remained retarded in development, while the third and fourth premolars were more progressive. This tendency, for

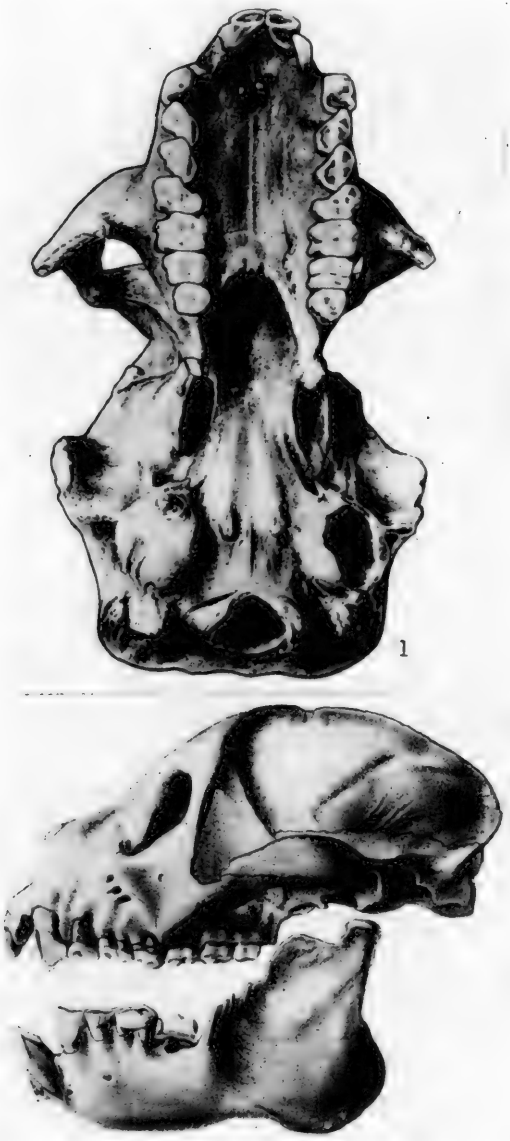


FIG. 73. SKULL AND LOWER JAW OF *Archæolemur edwardsi*, AN EXTINCT MONKEY-LIKE LEMUR FROM MADAGASCAR. ×½. AFTER STANDING

1 2

FIG. 74. UNDER SIDE OF THE SKULLS OF TWO MODERN INDRISINE LEMURS, *Propithecus* (1) AND *Indris* (2)

1.—*Propithecus diadema*. Amer. Mus., no. 31,253. ×1.

2.—*Indris indris*. Brit. Mus., 48.10.28.1. ×1.

In *Propithecus*, the first and second upper-molars bear two rows of W-shaped crests. In *Indris*, the W-shaped pattern is becoming obsolete and the cusps are more conical.

the premolar series to differentiate into two contrasting parts, the anterior part consisting of the small or reduced p^1 and p^2, and the posterior part consisting of the progressive p^3 and p^4, is highly developed, not only in the Indrisidæ, but also in several other groups, such as the Old World primates, including man. In the final stage of this evolution, the first and second premolars disappear entirely and the remaining premolars are homologous with the third and fourth of the primitive placental dentition. *This important fact seems to be little appreciated by those odontologists who do not recognize the fact that the tooth immediately in front of the molars, in all primates, is the homologue of the fourth premolar of primitive placental mammals.*

In all primates the elimination of the two anterior premolars is probably correlated with the shortening of the face, with the marked increase in size of p^3 and p^4, and often with the anteroposterior lengthening of the molars. When, as in the Indrisidæ and many apes, the upper canine becomes considerably enlarged, its posterolingual side comes into secondary articulation with the anteroexternal side of the anterior premolar, which is the second of the primitive series. This lower premolar thus becomes more or less enlarged. Up to this point, its tendency was to become like p_4, which in turn was tending toward the molar pattern; but, when p_2 comes into relation with the upper canine, its protoconid becomes enlarged and pointed, so that in *Propithecus diadema*, of the Indrisidæ, this tooth is almost caniniform in appearance. *This illustrates the general principle that individual teeth, like other parts of the skeleton, tend to assume the form required of them by their topographic position and functional relations to the surrounding parts.*

In the Indrisidæ and, more particularly, in the Archæolemuridæ, the true canines are taken over into the incisor series; and, in the latter, they tend to become enlarged, procumbent, and opposed by both the central and the lateral incisors. The tendency for the lower canines to become incisiform, and to oppose the upper incisors, is carried to an extreme in *Chiromys*, the Aye-aye, in which a single pair of upper incisors have become enormously enlarged and compressed, and opposed to a similar pair of pointed and enlarged lower teeth. The lower pair have often been regarded as incisors, but it is far more probable that they are enlarged canines. The almost rodent-like

FIG. 75. SKULLS OF TWO DIVERGENT MEMBERS OF THE INDRISIDÆ

1.—A dolichocephalic, dolichopic, type: *Indris indris*. Brit. Mus., 48.10.28.1. ×1.
2.—A brachycephalic, brachyopic, type: *Avahis*. ×2.

FIG. 76. SKULL OF THE AYE-AYE, *Chiromys madagascariensis*, A HIGHLY SPECIALIZED LEMUROID. COLLEGE OF PHYSICIANS AND SURGEONS, LONDON. ×1

The rodent-like front teeth are used to pierce the bark of trees; in the incisions thus made, the animal inserts its extremely attenuated, elongate, third finger to extract the grubs upon which it feeds. In correlation, perhaps, with the soft character of the food, the molar teeth are of degenerate type.

front teeth of the Aye-aye, and the correlated modifications in the form of the lower jaw, zygomatic arch and alveolar process, deceived some of the early investigators into grouping this animal with the rodents, but thorough comparisons of its osteology and anatomy soon indicated its proper place in the system. Its rodent-like appearance is found, on analysis, to be extremely superficial and to be manifested in characters which have been independently acquired in many widely removed phyla of mammals. In correlation with its habit of eating soft bodied grubs, its molar teeth are small in size and degenerate in pattern.

IV. SUMMARY AND CONCLUSIONS FOR PART II

After the evolution of mammals from mammal-like reptiles, in the early part of the Age of Reptiles, and after the subsequent origin of the tritubercular type of molars (as discussed in Part I of this work), the primitive mammals, represented perhaps by *Amphitherium* of the Middle Jurassic of England, probably gave rise (in the latter half of the Age of Reptiles) to two great series: the "marsupials" and the "placentals." The evolution of the molar patterns in the marsupials closely paralleled that in the placentals; and, likewise, has been traced by several investigators from a primitive triangular type, still largely preserved in the opossums, into the diverse shearing, cutting, crushing and grinding molars of the existing marsupials.

In Part I a study of the occlusal relations of the upper and lower teeth of the marsupials was shown to be requisite for an adequate understanding of the function and evolution of the several parts of the teeth. The same method has been followed in studying the evolution of the dentition of the Paleocene and later placentals. Emphasis was also laid upon the importance of not confining attention exclusively to the dentition, but of taking into consideration the evolution of other parts of the organization; and of keeping constantly in mind the taxonomic position, relationships, and evolution, of the organisms whose dentitions are studied; on the ground that when only one or two terminal and widely separated twigs of the great phylogenetic tree are compared, the observer is likely to be deceived into mistaking both fortuitous and convergent resemblances for genuine homologies.

The extinction of the giant reptiles at the close of the Cretaceous was then noted; also, the apparently sudden immigration into the known collecting fields of the archaic placental orders in the Paleocene epoch. With regard to the origin of the placentals, some of the cranial and dental characters which may be safely assigned to the (as yet) undiscovered common ancestors of all the placental orders, were enumerated. The great collections of Paleocene and Eocene mammals in the American Museum of Natural History are, it was suggested, of signal importance to odontological science, because they afford cumulative evidence for the truth of the central proposition of the "Cope-Osborn theory of trituberculy," namely, that all the highly diverse molar patterns of later placental mammals may be traced back to primitive tritubercular types.

In connection with the time honored problem of the origin of the tritubercular molar patterns of Paleocene and Eocene placentals, the writer, in common with many earlier authors, regards as erroneous the view that in the upper molars the true or original protocone is the internal apex of the trigon, while in the premolars it is the main external cusp; because, as pointed out by Wortman and others, the evidence tends to show that, as we pass backward from the anterior premolars through the fourth premolars to the true molars, the main tips of the premolar crown are homologous with the paracones + metacones of the molars; and, further, because the so-called "protocones" of the molars seem to have arisen as outgrowths from the internal basal cingulum, correlated with the development of the talonids or heels of the lower molars.

A further conclusion (p. 223), in line with the foregoing, is that in the upper molars of primitive mammals there are two trigons: (1) a primary or anterior trigon, consisting of the outer side of the tooth as a base and the tip of the paracone as its apex, and (2) a secondary or inner trigon, consisting of the para- and metacones as its base and the inwardly grown "protocone" as its apex. The primary trigon, it was argued (p. 224), was afterward often effaced in correlation with the transverse expansion of the hypoconid of the lower molar, because the hypoconid grew toward the buccal side, separating the para- and metacones, and also, as it were, pushing them toward the outer side of the crown, which often became reduced

in width. In the placental series, just as in the marsupials, the expansion of the talonid accompanied the (1) anteroposterior widening of the molars, their (2) division into anterior and posterior moieties, and the (3) reduction of the interdental spaces through the development of a postero-internal cusp or hypocone. Thus, while the "protocones," or internal spurs, were received into the basin of the talonids of the lower molars, the hypocones overlapped into the trigonid basins of the molars.

As the primary shearing and interlocking relations of the primitive trigonal upper and lower teeth were more or less superseded, new and diverse cutting and crushing adaptations were often developed by the elaboration of crests upon the surface of the crown (p. 226). The subsequent history of the molar patterns in the highly specialized ungulates and rodents demonstrates the high potentialities for subsequent modification of the primitive tritubercular type, and affords so many examples of the methods by which these complex patterns have been attained that the more simple results of molar evolution in the primates become readily discernible.

Coming nearer to the latter subject, I again (p. 230) suggested the futility of basing evolutionary conclusions on comparisons of conditions in widely unrelated groups, as when authors point to concrescence of teeth in elasmobranchs as evidence that in mammals each tooth represents the fused germs of a "dental family;" and I emphasized the importance of systematic comparisons according to the taxonomic or phyletic relationships of large groups. An outline of the history of the classification of the primates was then given (p. 231), culminating in the allocation by Linnæus of man, the apes, monkeys, and bats, to the order Primates; and the subsequent improvement of this classification down to the present time was noted.

Although the direct line of human ascent is but imperfectly known, synthetic studies on living and extinct primates, in the light of the palæontological history of other mammalian phyla. have yielded definite evidences as to the evolution of many human structures, such as the dentition. In this connection I find much that is true and enduring in the teachings of Huxley and other pioneers concerning human evolution, notwithstanding the fact that their results have recently been thrown lightly into the discard by Wood-Jones, a

polemic author with a strong bias for iconoclastic methods. To judge by his book on "Arboreal man" and by his brochure on "The problem of man's ancestry," Wood-Jones may fairly be classed with those anatomists who have, at most, a superficial acquaintance with vertebrate palæontology and yet do not hesitate to give judgment on phylogenetic problems, for the proper understanding of which long and wide experience with palæontological facts and principles is prerequisite.

I hope to show in Part IV of this paper, and in other publications, that Wood-Jones's leading thought as to "the basal mammalian primitiveness" of human anatomy has even less foundation in fact than his pronouncement that the lemurs certainly do not belong to the Primate stem (1918, p 27). In the present section (p. 232) and in my memoir on the American Eocene Primates, I have defended the older view that the lemurs are true primates; and have shown that a study of the evolution and adaptive radiation of their skull and dentition has yielded some important facts and principles bearing on the early stages of the evolution of the skull and dentition of man.

Concerning the origin of the primates it is held (p. 234) that the existing Menotyphla (a group of insectivores including the Tupaiidæ and Macroscelidæ) represent the comparatively little modified Cretaceous ancestors of the Primates; and the dentition of several Paleocene and Eocene "Insectivores," that probably represent more or less specialized survivors of this primitive ancestral group, are described and figured. Even in the existing Tupaiidæ, the molars are of primitive tritubercular type with small hypocones in the upper, and relatively narrow talonids in the lower, molars.

The evolution of the dentition in the primitive American Eocene lemuroids of the family Notharctidæ was then reviewed (p. 239). It was shown that, when first known, near the base of the Lower Eocene, these animals were of very small size, with insectivorous-frugivorous dentition; and that as we pass through ascending levels they steadily increase in size, culminating in *Notharctus crassus* at the summit of the Middle Eocene, the adults of which were about as large as a howler monkey. The lemur-like skulls and jaws in this family assuredly afford an early stage of primate evolution, tending to connect the higher primates with primitive placental mammals.

The same is true of their dental formula ($I\frac{2}{2}$ $C\frac{1}{1}$ $P\frac{4}{4}$ $M\frac{3}{3}$) and of the construction of all their teeth. The incisors and canines are of primitive type—not modified as they are in modern lemurs—and are fitted to give rise on the one hand to the procumbent incisors and canines of the lemurs, and on the other to the widened incisors and stout canines of the higher primates.

The evolution of the premolar series in the Notharctidæ, it was shown (p. 242), parallels that in many other Eocene phyla of placental mammals, and lends further support to the "premolar analogy" theory of the origin of the tritubercular molar. It was noted that the fourth upper molar, as in many other Eocene phyla, exhibits a tendency to divide into anterior and posterior moieties, that is, to assume the molariform pattern which is more fully realized in the last deciduous premolars. It was also observed that, in the Eocene primates, the ultimate and the penultimate premolars always differ considerably in pattern; whereas, in later or modern primates, these two adjacent teeth tend to become bicuspid and quite like each other, and unlike the molars. It was also held that, in later primates, where only two premolars on each side are present, the missing ones are the first and second of the primitive four. In the evolution of the lower molars were noted the gradual disappearance of the paraconid, correlated with the development of the hypocone and the reduction of the interdental spaces in the upper molars. We also noted the transverse widening of the talonid and the buccal growth of the hypoconid, this, as in other phyla, conditioning the anteroposterior elongation of the upper molars and the wider separation of the para- and metacones.

The Notharctidæ are distinguished from their cousins, the European Adapidæ, especially by the progressive development of the mesostyles and V-shaped para- and metacones; and by the origin of the postero-internal cusps by budding or fission from the antero-internal cusps; whereas, in the Adapidæ, the upper molars never develop mesostyles, and the postero-internal cusps arise as normal hypocones by the upgrowth of the posterior basal cingulum. These differences, we saw (p. 253), were associated with differences in the articular relations of the parts of the upper and lower teeth, and in the normal paths followed by the mandible in mastication. In the Notharctidæ,

the movement of the mandible progressively developed a more transverse component, the lower teeth engaging first on the outer side of the upper and passing obliquely across them toward the inner side; whereas, in the Adapidæ, the motion of the mandible was more vertical. There was therefore, in the latter family, no functional need of mesostyles; but, on the other hand, the transverse crests on the protoconules became emphasized, as in the Lemuridæ.

Forsyth Major's view, that the Lemuridæ have been derived from or are closely related to the Adapidæ, was adopted in preference to that of Stehlin, who holds that the Adapidæ have no near relations with the Lemuridæ. It was held that the observed conditions of the front teeth in the Lemuridæ have been derived from the primitive conditions seen in the primitive *Adapis sciureus* through a profound change of function, because the modern lemurs use their curiously specialized comb-like front teeth in cleaning their fur.

The Adapidæ have sometimes been regarded as standing in, or near, the line of ascent leading to the higher Primates; but this view is held to be erroneous on account of their resemblances with the Lemuridæ and partly because, as suggested by Leidy and by Wortman, the South American monkeys may have been derived from the Notharctidæ, as indicated by many resemblances in the skull and dentition. The peculiar procumbent, comb-like arrangement of the front teeth has been assumed independently in the Lemuridæ, Indrisidæ and Lorisidæ. It affords an example of the phenomenon that quite similar specializations are often independently evolved in families that have been derived from a common stock.

The opposite principle, that very wide differences may also be evolved in closely related stocks, is then illustrated by a brief review of the adaptive radiation of the dentition in the higher lemurs of Madagascar. Some of these animals became so monkey-like in appearance as to have led certain authors to the conclusion that they were really intermediate between monkeys and lemurs. The fact is, however, that they were monkey-like only in their "habitus" of recently adapted features, while they retained the old lemuroid "heritage" in many less conspicuous characters. This family (the Archæolemuridæ) further parallels some of the higher primates in the bilophodont specialization of the upper molars.

The indrisine lemurs (Indrisidæ) afford an instructive example of the reduction in the number of the premolars from four to two on each side, by the loss of the anterior two, probably conditioned by the shortening of the face and by the crowding of the dentition due to the increase in the anteroposterior diameter of the remaining cheek-teeth. The molars bear W-shaped crests on the para- and metacones, and thus parallel those of the Notharctidæ and other leaf-eating mammals.

In all the modern lemuriform primates, the lower canine is taken over into the incisor series; and the second or third lower premolar becomes more or less caniniform and opposes the upper canine. This illustrates the important general principle that individual teeth, like other parts of the skeleton, tend to assume the form required of them by their topographic position and functional relations to the surrounding parts.

The case of *Chiromys* (p. 264), which was regarded by early zoölogists as a rodent but was soon shown to belong with the lemuroid primates, illustrates a fact bearing on the taxonomic history and relationships of man, namely, that the taxonomic system of the present time is the end-result of innumerable detailed studies on the anatomy and palæontological history of the vertebrates; and, in consequence, the status of the vast majority of known mammals has been closely scrutinized, and many erroneous allocations, due to deceptive resemblances brought about by convergent evolution, have been detected and the intruding forms transferred to their proper places in the system.

(End of Part II)[5]

[5] The manuscript of Part III of this review has been received for publication in the next (September) issue of this JOURNAL. The bibliography will be appended to the concluding part, in the December issue.—(Ed.)

PLATE 5

Homologies of the external, middle, and internal row of cusps in the premolar-molar series of primitive placentals and marsupials. The figures are arranged according to the geological horizon of the genera.

The *red* series includes the main tips of the premolars, and the para- and metacones of the molars.

The *green* series includes the primitive outer row, which gives rise in later forms to the external cingulum and its cusps.

The *yellow* series includes the internal spur of the premolars and the so-called protocones of the molars.

A–D.—Zalambdodont insectivores. In these, the red series becomes predominant, growing inward, as the yellow series is reduced to a vestigial condition associated with a secondary reduction of the talonid.

E.—*Dryolestes*. The main tips of the molars appear to be homologous with the apices of the premolars and, therefore, to belong to the red series. The yellow series is possibly represented by the internal cingulum of the molars.

F.—*Apternodus*, an Oligocene forerunner of the modern Cape Golden Mole (*G*). Here we seem to have the primary trigon with its apex (red) still undivided, but this is possibly secondary. It is surely correlated with the lack of a talonid in the lower molars.

H.—*Didelphodus*. A primitive Eocene insectivore, in which the three series of cusps are all well developed. The para- and metacones are moderately separated in correlation with the moderate transverse diameter of the talonid (Compare *fig. 47*).

I.—*Proscalops*. A highly specialized insectivore, in which the para- and metacones are widely separated and the talonid is wide.

J.—*Tricentes*. A primitive carnivore with reduced outer cusps (green row) and well developed inner row (yellow). The secondary trigon has replaced the primary trigon.

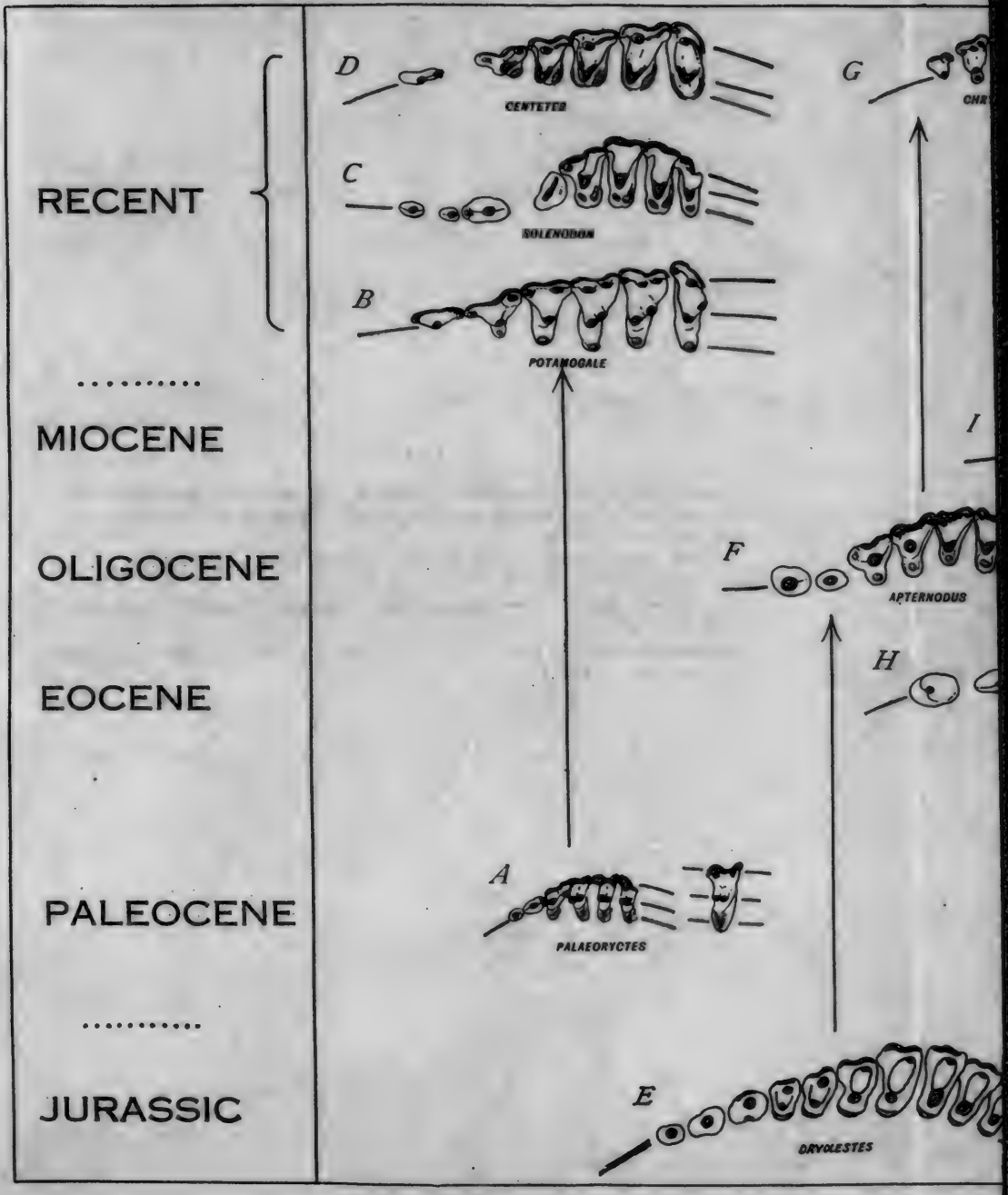
K.—*Peralestes*. In this Jurassic trituberculate only the primary trigon is developed.

L, M.—Modern polyprotodont marsupials (survivors of the Upper Cretaceous marsupials), in which the outer (green) row is strongly developed.

N.—Primitive Eocene condylarth, with reduced outer row and large inner row.

O.—Primitive tarsioid primate.

P, Q, R.—Primitive leptictid insectivores.


RECENT
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MIOCENE
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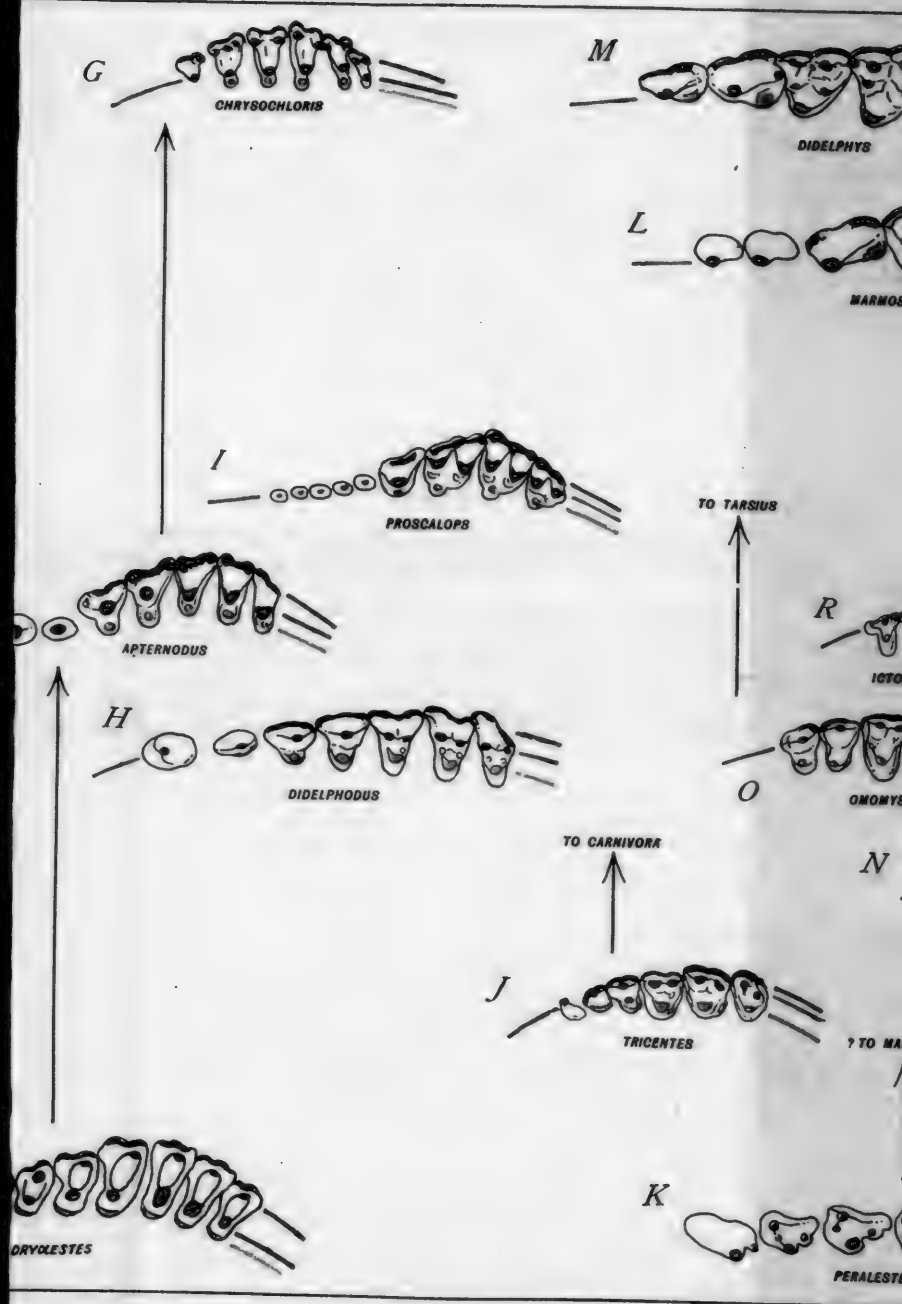
G
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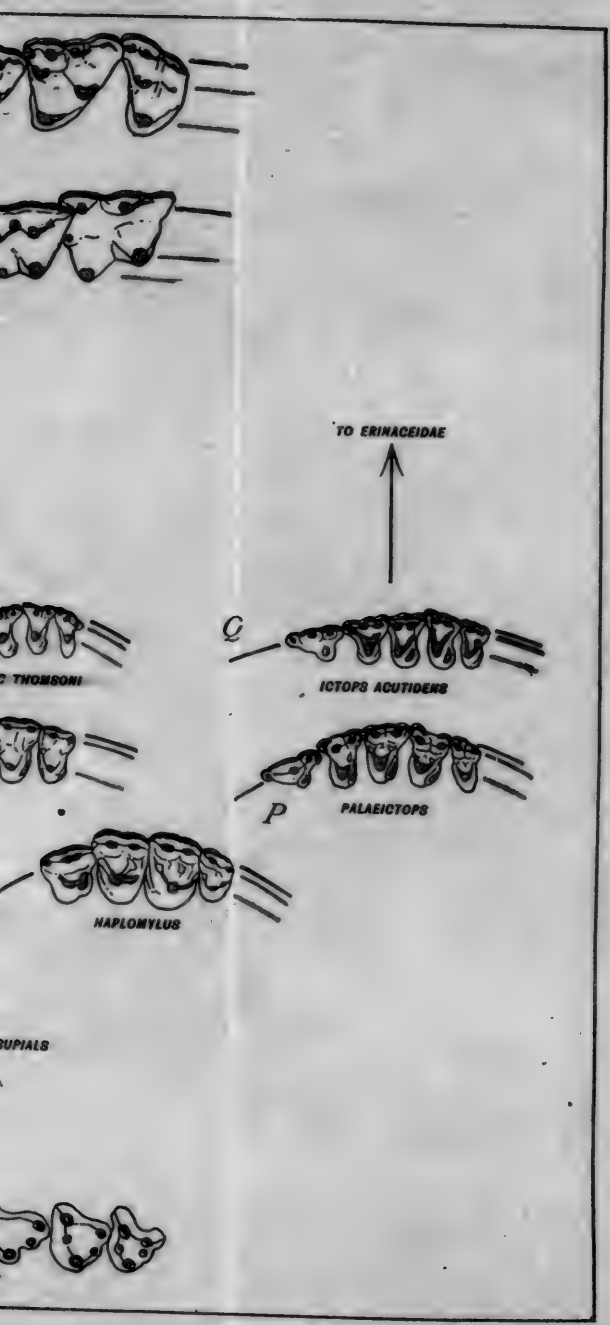

TO ERINACEIDAE
C
ICTOPS ACUTIDENS
P
PALAEICTOPS
HAPLOMYLUS

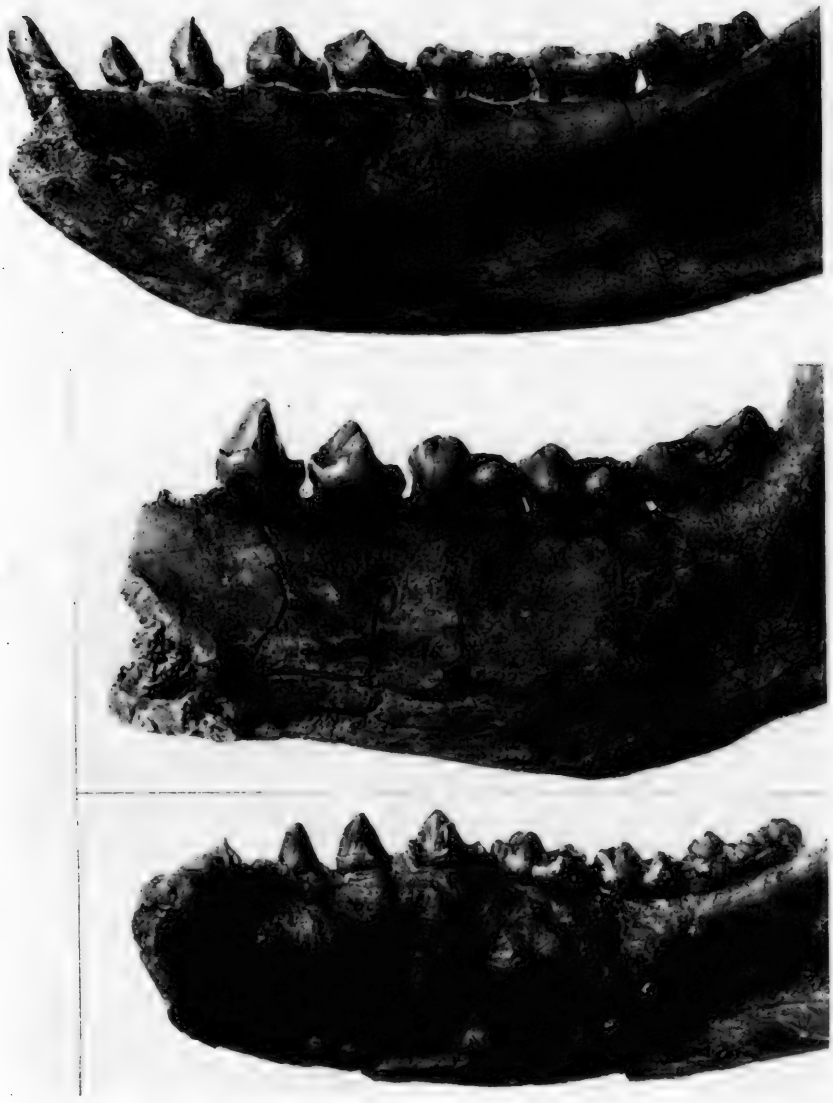
Plate 6

Medial aspect of the right mandibular ramus in three species of Eocene Notharctidæ from successive horizons, showing a rapid increase in size of jaw and a slow evolution of the third lower premolar. ×3.

1.—*Pelycodus trigonodus*. Lower Eocene, Gray Bull formation, Wyoming. Amer. Mus. Nat. Hist., no. 16,843.

2.—*Pelycodus jarovii*. Lower Eocene, Lysite formation, Wyoming. Amer. Mus. Nat. Hist., no. 15,624.

3.—*Notharctus osborni*. Middle Eocene, Lower Bridger formation, Wyoming. Amer. Mus. Nat. Hist., no. 11,466.



(Gregory: Evolution of the Human Dentition)

PLATE 7

Evolution of the upper premolar-molar series in species of Eocene Notharctidæ from successive geological horizons.

1.—*Pelycodus ralstoni*. Lower Eocene, Sand Coulée formation, Wyoming. Amer. Mus. Nat. Hist., no. 16,089.

2.—*Pelycodus frugivorus*. Lower Eocene, Gray Bull formation, Wyoming. Amer. Mus. Nat. Hist., no. 15,022.

3.—*Notharctus nunienus*. Lower Eocene, Lost Cabin formation, Wyoming. Amer. Mus. Nat. Hist., no. 4,735.

4.—*Notharctus crassus*. Middle Eocene, Upper Bridger formation, Wyoming. Amer. Mus. Nat. Hist., no. 11,982.

(Gregory: Evolution of the Human Dentition)

A FURTHER STATEMENT REGARDING "A PLAN TO COMPILE AND PUBLISH AUTHENTIC INFORMATION AND AUTHORITATIVE OPINION ON PROBLEMS CONCERNING PULPLESS TEETH AND PULP DEVITALIZATION"

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The issue of the JOURNAL OF DENTAL RESEARCH, for December, 1919, presents a statement of my purpose to endeavor, through the agency of a questionnaire, to obtain a consensus of current opinion and practice "relative to problems concerning pulpless teeth and pulp devitalization." In that statement I said:

"During the past few years much has been done and much more said relative to problems concerning pulpless teeth and pulp devitalization. Every physician, dentist, and patient, is vitally concerned in this matter. In the hope that a uniform manner of handling these cases may be established, it has been thought advisable to collect, compile, and classify, available information in this relation.

"Accordingly, a questionnaire has been prepared covering all phases of the problem. This questionnaire will be sent to practitioners of medicine and dentistry, who, on account of their high professional standing and extended experience, are in a position to lend valuable assistance in the execution of this project. The number of practitioners who will receive the questionnaire is sufficiently large to warrant the expectation that very broad, comprehensive, and diverse, views will be recorded. Incidentally, this plan will afford a very excellent opportunity to correct some misunderstandings which have occurred, and will do much to clear the atmosphere surrounding root-canal procedures and the status of pulpless teeth.

"After the work is completed, the questions and answers will be published in book form, and made available, at a low price, to members of the dental and medical professions.

"*All income from the sale of the book, over and above the cost of publication, will be donated to the endowment fund of the Journal of Dental Research.*"

Copies of the questionnaire are being distributed in accordance with the purpose and plan outlined above. The questions in the questionnaire are quoted below (the numerals are those of the pages of the questionnaire on which the questions individually appear).

(3) In the treatment of vital deciduous teeth, where the decay is so extensive that its entire removal will mean the exposure of the pulp, what do you advise and what is your procedure? Also, how do you proceed where the pulp is already exposed?

(4) In the treatment of deciduous teeth where the pulps have become non-vital and infected, what is your procedure and what do you advise?

(5) In case the root-ends of permanent teeth are not completely formed and the pulp has decomposed, what is your procedure and what do you advise?

(6) In case the root-ends of permanent teeth are not completely formed, and the pulp is still vital but exposed, as a result of decay or trauma, what is your procedure and what do you advise?

(7) In case the vital pulp is covered with a thin layer of decalcified dentine, what is your procedure and what do you advise?

(8) At what age do you consider it good practice to begin bridgework which necessitates cutting into vital teeth? Do you consider that the location in the mouth is a governing factor?

(9) When permanent teeth of young patients are extracted on account of apical infection, do you retain the spaces with orthodontic appliances, use bridgework, or pay no attention to the spaces created by the extraction?

(10) Where deciduous teeth are extracted, do you, under any circumstances, advise retaining the space, with orthodontic appliances, for the eruption of the permanent teeth?

(11) What were the conditions that caused the death or removal of so many pulps in the past? To what extent are these conditions now under control and pulp removal unnecessary?

(12) What are the causes of pulp-death over which we still have no control?

(13) In a case where decay is in actual contact with a vital pulp, do you advocate (a) removal of all decay and attempted pulp capping; (b) removal of the decay followed by pulp removal; (c) leaving just enough decalcified dentine to prevent actual exposure and giving the case a treatment? (c′) What does such treatment consist of? How long have you practiced it? Do you consider it a good procedure to follow?

(14) How early do you begin oral prophylaxis for your patients?

(15) Outline your plans for preventing decay and pulp-death in the teeth of young patients.

(16) Is it your habit to give the mouths of your patients prophylactic supervision during the time they are in your care? If so, how frequently do you see the patients for this work?

(17) In deciding why the radiograms of some non-vital teeth show areas indicative of apical disease, and some do not, and also why some persons with such teeth display symptoms suggestive of focal infection while others do not, is it probable that different factors contribute to the two conditions at the ends of the roots? Be sure to mention whether or not you believe the development of apical infection is solely a matter of diminished resistance on the part of the patient.

(18) In the case of a non-vital tooth showing apical infection, outline methods by which such infection can be removed and the tooth retained. Do you consider that such procedure gives permanently satisfactory results?

(19) Approximately what number of non-vital non-infected teeth would you advise leaving in any one mouth (a) in the absence of symptoms of focal infection; (b) in the presence of symptoms of focal infection? Do you make any distinction, in this regard, so far as age of the patient is concerned?

(20) In a case showing symptoms of a focal infection, to what extent would you go in trying to save a non-vital tooth which apparently had no apical infection, provided such a tooth was a valuable factor in the reconstruction of the mouth?

(21) In case a radiogram shows a tooth with a pulp-chamber and portions of one or more roots only partly filled, how do you determine whether the unfilled apical portions of the roots contain vital pulp-tissue, or non-vital tissue, or no pulp-tissue at all—all three conditions being supposedly free from apical infection?

(22) In the reconstruction of a mouth, do you believe in removing any non-vital teeth that do not show apical pathology, radiographically?

(23) Do you believe in root resection as a permanent operation? On which teeth? Do you feel that, in such an operation, the pulp-canal and dentine should receive special attention? Of what should such treatment consist?

(24) Should a tooth which is abscessed be extracted during the active process of inflammation or is such an operation as a routine procedure contraindicated?

(25) For the extraction of a considerable number of teeth in a case of serious infection, how do you proceed? Do you remove a few at a time or all at one operation?

(26) Do you consider that unerupted or impacted teeth, regardless of their location, should be removed when they cannot be brought into their proper places in the arch?

(27) Under what conditions and in what locations in the mouth, is it justifiable to remove a decomposed pulp and to fill the canal or canals? Give a list of such conditions.

(28) Under what conditions, and in what locations in the mouth, is it justifiable to remove a vital pulp and to fill the root-canals with an artificial substitute? Give a list of such conditions.

(29) When a tooth, to be extracted, has an apical infection, should the infected region be curetted after the extraction, or should it be left undisturbed? Would your decision to curette be the same if the granuloma came out with the root?

(30) Upon what basis do you decide what to do with the various teeth in a mouth which contains a great number of non-vital teeth; some showing apical involvement and some not; some with partially and others with completely filled roots; some with exposed vital pulps and some with dead pulps? Go sufficiently into detail so that your answer may serve as a guide in general practice.

(31) In the case of a maxillary sinus infection that does not respond to treatment, what disposition would you make of any non-vital molars or bicuspids on the side affected?

(32) In the reconstruction of a mouth, would you advise the removal of one or more vital pulps, if that procedure enabled you to use a more satisfactory type of bridge than would be possible if such pulps were not removed? If you ever advise such a procedure, does the patient's age and condition influence your decision?

(33) From a histological standpoint, is the removal of a tooth pulp and the sealing of the canal a feasible operation? If not, why not? If so, under what conditions?

(34) Do you believe in ionization? Why? To what extent?

(35) In case a vital pulp has been removed, and a radiogram shows that the end of the root was reached and a slight apical injury probably resulted, due to the severing of the pulp tissue, do you feel that the result of the operation will be influenced in any way by the presence of mouth infection, pyorrhea alveolaris, or apical abscesses? What do you do in such cases?

(36) In the case of a patient who fractures the two upper central incisors, what is your procedure (a) when the pulps are exposed; (b) when they are not exposed but you fear they will die? To what extent does the patient's age influence your decision?

(37) In case the dentine of a non-vital tooth is not infected, and is surrounded by or encased in living cementum, which is in turn surrounded and nourished by a normal vital peridental membrane, would you consider such a tooth a foreign body? Will it become infected, and will nature try to throw it off?

(38) Do you believe in treating diseased apical tissue through the canal or do you believe in surgical removal of such tissue?

(39) Do you consider that a diseased tooth with infected dentine is more liable to have a deleterious effect on the surrounding tissues, even though the canal was cleansed of the infected pulp, than would be the case if the symptoms of inflammation of the tooth pulp were detected early and the pulp removed before it had become infected?

(40) To what extent do you consider x-ray evidence final in determining the occurrence, extent and nature of apical pathology?

(41) In orthodontic treatment, what causes pulp-death during the process of moving the teeth and how can such a cause be eliminated? What do you do or advise when pulp-death occurs for this reason?

(42) Do you think one should differentiate between teeth which contain infected pulps and teeth from which healthy pulps have been removed, in determining whether or not non-vital teeth may be retained?

(43) In correcting a case of malocclusion, do you first make a complete x-ray examination and vitality test of all the teeth in order to locate the non-vital or unerupted teeth? If you make an examination, partial or complete, what do you do with the non-vital teeth present? Do you complete your realignment with them in place or do you advise their early extraction? What do you advise in case the third molars are impacted? What do you think of the alveolus surrounding non-vital teeth as compared with that surrounding vital teeth?

(44) In your opinion, is dentine infected by preparing cavities for fillings and then allowing some time to elapse before placing the filling, no precaution being taken to seal the cavity in the interim and to prevent admission to it of saliva?

(45) May a non-vital tooth be free from infection?

(46) May a vital tooth have an infected peridental membrane (aside from that of a pyorrheal condition?

(47) Does an infection at a root-end come from (a) the tooth itself (a1) through the canal (a2) by the presence of infected dentine; or (b) is it carried there from the blood stream independently of infection in the canal? In case you consider that an apical infection comes from the tooth itself or the canal, how do you account for (a) the presence of infection in canals

and at apices that have undamaged natural crowns? (b) If you consider that such an infection comes from the blood stream, why is it that, in a given mouth, some non-vital teeth are not infected and others, adjacent, may be badly infected?

(48) Do you believe that the presence of silicate fillings causes pulp death? If so, how do you prevent such action?

(49) If you take the stand that all pulpless teeth, regardless of radiographic findings and regardless of whether the patient is in good or poor health, should be extracted, do you put any age limit on such procedure? Why?

(50) Do you consider that the handling of hospital cases, relative to problems of pulpless teeth, should govern the management of patients in private practice?

(51) What do you think of the extraction of pulpless teeth that radiographically show no infection, in patients in good health?

(52) How do you view the construction of extensive restorations which call for the use of pulpless teeth as abutments?

(53) What is your opinion on the use of extensive stationary bridges cemented to vital-tooth abutments?

(54) In case you had a pulpless tooth and a vital tooth proximating, with the pulpless tooth apparently free from infection and with a space adjacent to the pulpless tooth due to loss of teeth: Would you remove the pulpless tooth and carry the bridge to the vital tooth or not?

(55) Please suggest any other questions you think should be answered.

It will be impossible to send copies of the questionnaire to all from whom it would be desirable to obtain expressions of opinion, and statements of experience, on the various subjects included within the scope of these questions. For this reason the questions are published here for the information of all who may be interested.

I cordially invite my dental colleagues, in this country and abroad, who may not receive copies of the questionnaire, to send me independently, before October 1, 1920, such responses as they may be disposed to make to these questions, for the furtherance of the professional project outlined above. It is requested that all such responses be written in conformity with the following outline of the preferred mode of discussion, as specified on page 2 of the questionnaire:

"In order that the presentation of answers may be as uniform as possible, responses should be written in accord with the following plan:

"(1) Give your answers to the questions as *directly* and *briefly* as possible in each instance.

"(2) Give your practical *observations* on the subject of each question.

"(3) Tell what your *conclusions* are.

"(4) In stating *opinions*, give also the *verifiable* facts that support or appear to justify your opinions; and sharply distinguish in all your answers between what you *know* to be true (fact) and what you *believe* to be true (faith).

"(5) When you advise or recommend any procedure, state specifically *why* you commend it.

"(6) Give any *statistics* you may feel like making public.

"(It is, of course, not expected that statistics will always be obtainable, but whenever given they will be appreciated.)"

I hope to receive the effective collaboration of all who may be interested; and to be favored with assistance at once so prompt and extended, that the proposed publication of the classified responses may be made early in the fall of 1920.

933 Metropolitan Bank Building.

EXPERIMENTAL STUDIES OF THE VALIDITY OF ADVERTISED CLAIMS FOR PRODUCTS OF PUBLIC IMPORTANCE IN RELATION TO ORAL HYGIENE OR DENTAL THERAPEUTICS

3. Mennen's Cream Dentifrice, Advertised as an Acid Dentifrice, is Alkaline in Reaction

MAXWELL KARSHAN and WILLIAM J. GIES

Biochemical Laboratory, Schools of Medicine and Dentistry, Columbia University, New York City

I. ADVERTISED CLAIMS SUBJECTED TO INVESTIGATION

Some of the claims that have been, and continue to be, made publicly in behalf of Mennen's Cream Dentifrice are summarized below from circulars accompanying tubes of the product recently purchased in the open market in New York City.

1. "Research shows that certain fruit acids," when introduced into the mouth . . . . (a) "stimulate the flow and (increase the) alkalinity of saliva, so that between times, all day and all night, the marvelous protective work of nature can go on;" and (b) "their use (fruit acids) not only benefits the teeth during the cleaning process, but have (has) a continuing good effect." ("On this scientific basis," it is said, "Mennen's Cream Dentifrice was developed. *This is its reason for existence. It upsets the preconceived ideas of what a dentifrice should be.*")

2. "An alkaline dentifrice counteracts—for a moment—the destructive acids (of fermentation in 'acid mouth') but it also diminishes both the flow and the alkalinity of the saliva, and, in time, (also) its secretion (saliva) because of the inhibitory action of an alkaline (reaction) on the salivary glands. It further hardens the plaques instead of softening them." . . . . "We are driven (here the circular quotes Pickerill) to the inevitable conclusion that alkaline dentifrices and mouth washes for the prevention of dental caries must be abandoned."

3. Mennen's Cream Dentifrice was developed on the "scientific basis" afforded by Pickerill's findings, and in accord with Pickerill's general conception regarding dentifricial stimulation of the flow of saliva, to the effect "that alkaline dentifrices and mouth washes for the prevention of dental caries must be abandoned" and suitably acid dentifrices (such as those suggested by Pickerill) used instead.

4. "Mennen's (Cream Dentifrice) introduces a fruit acid into the mouth, in the form of minute crystals which dissolve when the teeth are brushed. This fruit acid softens and breaks down deposits of tartar and the tiny invisible mucin 'plaques' beneath which the process of decay begins."

5. The fruit acid "introduced" into Mennen's Cream Dentifrice, according to the claims, is not only *added* to the mixture comprising the dentifrice, but also is *present* in the dentifrice *and acts in the mouth* as "fruit acid." A direct claim to this effect is indicated by the quotation in the last preceding paragraph above (4) and is implied also in the following "direction for use:" "Use sufficient water to thoroughly dissolve the fruit acid and give the desired copious refreshing lather."

II. FINDINGS IN AN EXPERIMENTAL INVESTIGATION OF THE CLAIMS OUTLINED ABOVE

We find as follows in a study of the contents of about fifteen tubes of Mennen's Cream Dentifrice, purchased at different times recently at widely separated stores in New York City.

A. This dentifrice is alkaline in reaction—*not acid, as claimed!* It is alkaline in reaction to alizarin, azolitmin, congo red, lacmoid, litmus, methyl orange, para-nitrophenol and Töpfer's reagent. The degree of alkalinity is relatively high. The dentifrice is alkaline to these indicators when they are applied, as solids or in solution, to the cream directly or to dilutions of it.

In titration tests of the alkalinity of the cream, it was found that the alkalinity per gram of cream (with *litmus* as the indicator) was neutralized by from 4 to 5 cc. of n/20 hydrochloric acid solution.

B. Phenolthalein, in solid form or in solution, added to or mixed with the cream itself, fails to indicate an alkaline reaction. When

however, the cream is mixed with water (less water than that recommended in the "direction for use" that is quoted above, "to thoroughly dissolve the fruit acid and give the desired copious refreshing lather"), the cream-water mixture becomes markedly alkaline to phenolthalein.

In titration tests of the alkalinity of the cream (treated with water in a volume similar to that of the combined quantities of water and saliva that may be ordinarily mixed with such a cream, when used as a dentifrice), it was found that the alkalinity per gram of cream (with phenolthalein as the indicator) was neutralized by from 3 to 4 cc. of n/20 hydrochloric acid solution.

The failure of the *undiluted* cream to show an alkaline reaction to phenolthalein, despite the relatively strong alkalinity of the cream that is shown by all the indicators named above, is not due to a condition of neutrality or acidity but to a special *interference* in this instance with the exhibition of alkalinity. An illustration of such "interference" is the fact that neutral commercial gum arabic in concentrated solution, mixed in moderate excess with various proportions of solutions of sodium hydroxid, sodium carbonate, or soap, prevents each of these three substances from showing, to phenolthalein, any of its normal alkalinity (in the same total volume of water). A similar illustration is the fact that mixtures of aqueous solutions of neutral gum arabic, sodium carbonate, and soap, in combinations that are alkaline to alizarin and to litmus, and non-reactive with phenolthalein, show an alkaline reaction to phenolthalein when such mixtures are diluted with water (a result analogous to that for the cream noted above). The cream contains water and alcohol. The latter may influence the behavior of the *undiluted* cream to phenolthalein.

C. Mennen's Cream Dentifrice contains a form of soluble carbonate, is not acid in reaction, and does not develop an acid reaction when it is mixed with water or saliva. When a tubeful of this dentifrice is mixed with a moderate excess of water, and then air, free from carbon dioxide, is passed first through this cream-water mixture and next through lime-water, by an ordinary quantitative aeration process from beginning to end, the amount of carbon dioxide that is thus taken out of the cream-water mixture, as shown by the condition of

the lime-water, is insignificant—less than the quantity that might be reasonably expected to arise (by aeration) from a small proportion of sodium bicarbonate in the mixture, *in the absence of acid.*

The reduction in alkalinity of the lime-water, induced by the carbon dioxide that was completely transferred from *all the material in a tube-ful* of the cream, was equal to the reduction in alkalinity that would have been caused by the addition of only from 5 to 6 cc. of n/20 hydrochloric acid solution.

When, however, acid is added to the cream-water mixture that has failed to yield more than an insignificant amount of carbon dioxide by the method just outlined, then carbon dioxide is rapidly and abundantly evolved from contained carbonate and promptly appears in the lime-water as precipitated carbonate of calcium.

D. Filtrates from mixtures of Mennen's Cream Dentifrice with water, in smaller to larger degrees of dilution than such as would occur in the mouth during the use of this cream as a dentifrice, *completely lack precipitative power on mucin* in concentrated aqueous solutions of salivary sodium mucinate; and also *fail to dissolve slight quantities of freshly precipitated tri-basic calcium phosphate* suspended in water. These statements apply, also, to the cream-water mixtures containing so little water that the mixtures do not exhibit alkalinity to phenolthalein (though all ordinary aqueous mixtures of this dentifrice are alkaline to the other indicators named above).

It is obvious, from these directly negative results, that the degree of any acidity that might be assumed to be indicated by the exceptional behavior with phenolthalein (noted above) is too slight to "soften and break down deposits of tartar and the tiny invisible mucin 'plaques.'"

III. CONCLUSIONS

Mennen's Cream Dentifrice is not an acid dentifrice. *Its reaction is alkaline.* Any power that Mennen's Cream Dentifrice may have, to "soften and break down deposits of tartar and . . . . mucin 'plaques,'" and to "stimulate the flow and (increase the) alkalinity of saliva," must be due to some other agency than the advertised, though non-existent, acidity of this dentifrice.

IV. CUMULATIVE SUMMARY OF FINDINGS[1]

Mennen's Cream Dentifrice. The advertised claims that, *used as a dentifrice*, Mennen's Cream Dentifrice is (a) acid in reaction and that, (b) through the agency of acidity, this dentifrice "softens and breaks down deposits of tartar and . . . . mucin 'plaques,'" and "stimulates the flow and (increases the) alkalinity of saliva," *are claims that are wholly unwarranted.* Karshan and Gies: JOURNAL OF DENTAL RESEARCH, 1920, ii, p. 293. *Findings in support of the advertised claims stated above:* Asserted only in promoters' advertisements; no other confirmatory findings are known to the authors named above.

Pepsodent. The advertised claims that, *used as a dentifrice*, Pepsodent (a) completely removes mucin plaques from teeth, and (b) effectively prevents re-formation of such plaques on teeth, by a digestive action of contained pepsin, "activated" by admixed acid calcium phosphate, *are claims that are wholly unwarranted.* (1) Gies: *Journal of the American Medical Association*, 1917, lxviii, p. 1278 (reprinted in the JOURNAL OF DENTAL RESEARCH, 1919, i, p. 507); (2) Franke and Gies: *Journal of the Allied Dental Societies*, 1917, xii, p. 360; (3) Franke and Gies: JOURNAL OF DENTAL RESEARCH, 1919, i, p. 511. *Findings in support of the advertised claims stated above:* Asserted only in promoters' advertisements; no other confirmatory findings are known to the authors named above.

[1] A summary of findings is appended to each of the papers in this series. These summaries are cumulative, in the sense that each includes the summaries of the papers preceding it. This plan enables us to present, recurrently, the sum of the findings in this series of investigations.

EXPERIMENTAL STUDIES OF THE VALIDITY OF ADVERTISED CLAIMS FOR PRODUCTS OF PUBLIC IMPORTANCE IN RELATION TO ORAL HYGIENE OR DENTAL THERAPEUTICS

4. Pepsodent "Bulletin No. 4" Does Not Show that Pepsodent Exerts Appreciable Digestive Action on Dental Mucin Plaques

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CONTENTS

I. Introduction 299
II. The contents of Pepsodent "Bulletin No. 4" 300
Method A 301
Method B 302
Conclusions 303
III. Discussion of the import of Methods A and B, and the significance of the conclusions at the end of "Bulletin No. 4" 303
Method A 303
Method B 306
Conclusions 309
IV. General remarks 310
V. Conclusions 311

I. INTRODUCTION

Since the publication of the second paper in this series,[1] I have been asked, repeatedly, to discuss publicly "Bulletin No. 4," issued from the Pepsodent Laboratories, July 23, 1919. I do so briefly and directly below.

Before proceeding to this discussion, the reader is reminded of our previous statements about the feebleness and lack of utility of the

[1] Franke and Gies: *Journal of Dental Research*, 1919, i, p. 511.

pepsin in, and as a part of, Pepsodent used as a dentifrice, which were summarized on p. 512 as follows:

"Pepsodent does not possess appreciable digestive power on dental mucin plaques when Pepsodent is applied as a dentifrice to the teeth.

"The pepsin in Pepsodent is too small in proportion, or too weakly 'assisted' by the acidity of the Pepsodent, or both, to enable Pepsodent to show more than insignificant digestive action on mucin and other proteins, even after hours of contact of Pepsodent with mucin and other proteins, under the most favorable conditions of temperature, time, concentration, and contact, for the elicitation of signs of digestive power and action.

"The 'activation' that the acid calcium phosphate in Pepsodent may afford the pepsin in Pepsodent—and on which the digestive activity and plaque-removing power of the pepsin is said to depend—is insignificant in degree and unimportant in effect.

"The weak acidity of the acid calcium phosphate in Pepsodent—on which the digestive action of the pepsin avowedly depends—is so promptly neutralized, by the basic substances in saliva, that the insignificant activating influence of this acidity on the pepsin, at the moment of the introduction of Pepsodent as a dentifrice into the mouth, is promptly reduced to nothing and the advertised foundation for the activity of the pepsin completely swept away."

The reader is requested to note particularly that the foregoing statements relate to pepsin *in, and as a part of*, Pepsodent *used as a dentifrice*.

II. THE CONTENTS OF PEPSODENT "BULLETIN NO. 4"

"The object of this Bulletin," says its author, "is to describe and illustrate methods by which the proteolytic activity of the pepsin in Pepsodent may be determined." Two methods for this determination are described. They are quoted verbatim below, respectively as "Method A" and "Method B"—the italics in each instance are mine. [The author of "Bulletin No. 4" does not state that these methods are intended for the *determination of the proteolytic power of Pepsodent as Pepsodent*, but only of the "*pepsin* in (*from*) Pepsodent!"]

Method A

"Immerse a hen's egg, which is not less than five nor more than twelve days old and has been kept in a cool place, in boiling water during twenty minutes. As soon as the egg has sufficiently cooled to handle it, remove the pellicle and all the yolk; at once cut the coagulated albumen into cubes each weighing about 2 grams.

"Mix the contents of *one regular-sized tube of Pepsodent* with 50 cc. of distilled water, stirring vigorously to insure thorough mixing. By means of a water-bath, warm this mixture to 37.5°C.

"Having prepared the Pepsodent suspension and the freshly coagulated egg-albumen cubes as described above, suspend the latter in the former, for *fifteen minutes*, by means of a platinum wire and silk thread, with occasional stirring, at a temperature of 37.5°C.

"At the end of fifteen minutes, remove the albumen cubes from the Pepsodent suspension, and at once, without washing, triturate them in a small glass mortar until a finely divided condition of a pasty consistency results. Each cube should be triturated separately and digested in individual digestion tubes. Transfer the triturated masses thus formed to digestion tubes containing *25 cc. of 11 per cent lactic acid. Shake vigorously* and digest in a water bath *at 52°C.*, with *frequent agitation* (once *every ten minutes*) for *two and a half hours. At the end of that time*, digestion will be practically complete and the coagulated albumen will be *almost entirely dissolved.* When the albumen cubes are taken from the Pepsodent suspension, they are covered with a layer of tri-basic calcium phosphate [$Ca_3(PO_4)_2$], the abrasive used in Pepsodent, which remains as a residue after digestion and which must not be confounded with undigested egg albumen.

"Controls must be run in connection with each digestion experiment. These are carried out according to the above described directions but omitting the fifteen minutes suspension step of the albumen cubes in the Pepsodent mixture.

"In place of lactic acid, an aqueous solution of soluble carbohydrates (glucose) may be employed and this, by fermentation, converted into lactic acid. *For experimental purposes the former process is preferred because it may be carried out in much less time.*

"The conditions described above have been chosen because it is believed that they operate *in some ways* under conditions which exist when Pepsodent is used as a dentifrice."

Method B

"*Mix the contents of one regular-sized tube of Pepsodent with 75 cc. of distilled water*, stirring vigorously to insure thorough mixing. Transfer this mixture to a cylinder of 100 cc. capacity and set it aside for seventy-two hours to subside.

"Immerse a hen's egg, which is not less than five nor more than twelve days old and has been kept in a cool place, in boiling water during twenty minutes. As soon as the egg has sufficiently cooled to handle it, remove the pellicle and all the yolk; at once rub the albumen through a clean, dry, hair or brass, No. 40 sieve, reject the first portion that passes through the sieve, and place 10 grams of the succeeding portion in a glass digestion tube.

"Pipette off 10 cc. of the clear supernatant fluid formed in the Pepsodent mixture and add it to the 10 grams of granulated egg albumen. *Add 50 cc. of hydrochloric acid, 0.3 per cent*, and shake vigorously until thoroughly mixed. Place this tube in a water-bath heated to *52°C. for two and one-half hours*. By means of a thin glass-rod, *stir the contents carefully every ten minutes*. If the pepsin in Pepsodent is active, the egg albumen will be *almost entirely digested*.

"The water-bath is best prepared from a 3-litre beaker and an ordinary paraffin bath, the beaker enabling the operator to observe the process constantly.

"A control tube should be run in connection with each experiment, consisting of the above method with the 10 cc. of Pepsodent fluid omitted. It will be noticed that no digestion takes place in the control tube. In cases of incomplete digestion, the column of albumen left may be compared with the control column and thus the relative activity may easily be determined.

"*The object of eliminating the abrasive* by subsiding is to remove it from the field so that the digestion process is more easily visible. Traces of abrasive may be carried into the digestion tubes and this will remain as insoluble matter. The latter should not be confounded with undigested egg albumen.

"The above process is essentially the process recognized by the United States Pharmacopoeia, IX, for the assay of pepsin. Slight modifications have been made to make the process more applicable to this preparation. These methods *in some ways* operate under conditions which exist when Pepsodent is used as a dentifrice."

"Another object" of the Bulletin, it is said, "is to show (with the aid of these methods) that the pepsin in Pepsodent remains active."

Results obtained with these methods are illustrated photographically. On the last page of the "Bulletin" is given the "Pepsodent formula."

Conclusions in "Bulletin No. 4"

The following "conclusions" are summarized at the end of the "Bulletin:"

"(1) Pepsodent contains the enzyme pepsin.

"(2) This enzyme, pepsin, is in an active state.

"(3) This enzyme is capable of rendering albumen soluble by means of digestion.

"(4) Time has very little, if any, effect on Pepsodent.

"(5) Pepsodent, after nearly three years, possesses all its proteolytic (digestive) power.

"(6) Pepsodent is free from substances injurious and destructive to oral tissue, for such destructive substances would soon completely destroy the sensitive enzyme pepsin."

III. DISCUSSION OF THE IMPORT OF METHODS A AND B DESCRIBED ABOVE, AND THE SIGNIFICANCE OF THE CONCLUSIONS AT THE END OF "BULLETIN NO. 4," QUOTED ABOVE

Method A

Method A is designed to enable the operator to concentrate on the albumen cubes, by adsorption, most if not all of any pepsin *in a whole tube of Pepsodent.* The cubes, with the pepsin in the Pepsodent-water mixture adherent to them, and with *all the other constituents of Pepsodent out of the way,* are immersed in an excess of 11 per cent (!) lactic acid solution, which activates the pepsin that sticks to the cubes, thus causing the digestion of the protein in the cubes. Digestion of the protein in the cubes under these conditions shows the *presence* of activatable pepsin in the Pepsodent-water mixture in which the albumen cubes were first immersed—but that's all it does show, so far as quality of Pepsodent is concerned.

This method gives no information on the action of pepsin *in, and as a part of,* Pepsodent *when the latter is used as a dentifrice.* It is not explained in the "Bulletin" why egg albumen instead of salivary

mucin was used as the protein to indicate the presence of pepsin in Pepsodent. The reader of the "Bulletin" is also not informed why each small cube of albumen (with pepsin sticking to it) was immersed, for the activation of the pepsin, in a large excess of such a strong acid as 11 per cent lactic acid solution *instead of in a solution of the substance that is said to activate the pepsin in Pepsodent*, namely, acid calcium phosphate (1.04 per cent). If the latter is of any real use as a pepsin activator, why was a large excess of strong lactic acid preferred to it by the author of Method A? Further, one wonders why it was necessary to warm the mixtures to 52°C., to obtain evidence of digestive power; and why, if the activity of the pepsin was not insignificant, it took several hours of such heating in an excess of the strong acid to demonstrate the exhibition of *some* peptic power? In what respects are these strikingly artificial conditions comparable with those that obtain in the mouth during the use of a dentifrice?

It is observable, also, that the protein, used to show the digestive power of the pepsin taken from Pepsodent, was not allowed to remain in the form of cubes, with their surfaces of definite though restricted extent, analogous to those of dental mucin plaques. Instead, in order to give further *special* help to the available pepsin, the protein (albumen) was finely divided by trituration.

The results with Method A, as illustrated in "Bulletin No. 4," show merely that there is *some* pepsin in Pepsodent, but obviously these results demonstrate nothing regarding the power or utility of this pepsin *in, and as a part of*, Pepsodent *used as a dentifrice*, for they relate to pepsin removed from and tested outside of Pepsodent.

It is stated, at the end of the description of Method A, that, "in place of lactic acid, an aqueous solution of soluble carbohydrates (glucose) may be employed and this, by fermentation, converted into lactic acid. *For experimental purposes the former process is preferred because it may be carried out in much less time.*" Readers of the "Bulletin" will probably wonder with me why, assuming that the author of the "Bulletin" was not unduly hurried in its preparation, there is no illustration among the twelve in the "Bulletin" to show that the above mentioned alternative procedure, involving the action of acid produced by the fermentation of glucose solutions, is nothing more than an assumption.

At the end of the description of Method A, it is also said that "the conditions described (in that method) have been chosen because it is believed that they operate *in some ways* under conditions which exist when Pepsodent is used as a dentifrice." In view of the fact that the outstanding feature of Method A is the adsorptive separation of pepsin from Pepsodent, and the concentration of the pepsin on the protein to be digested, with the complete elimination of all the other constituents of Pepsodent from the field of action, one wonders what the phrase, "in some ways," in the above (last) quotation is intended to suggest. Certainly, "in some ways" is a purely speculative allusion in this relation.

Perhaps the author intends to suggest by the phrase, "in some ways" (although he does not say so), that dental mucin plaques (like the egg-albumen cubes) adsorb pepsin from Pepsodent, when the latter is used as a dentifrice, and that then the plaques are digested by the pepsin that is thus gradually concentrated on the plaques. But how, if this is the author's idea, would the pepsin thus adsorbed on the plaques be *activated* so that the pepsin would digest the plaques? Surely not by acid calcium phosphate in, or from, the Pepsodent that yielded the pepsin, for the author of the "Bulletin" *ignores acid calcium phosphate as an activator* in Method A; and it is well known to be practically useless as a peptic activator (despite its advertised employment for this purpose in Pepsodent).

Possibly, and this seems to be the only alternative under the circumstances, the author intends to suggest (although he does not say so) that pepsin is *adsorbed into dental mucin plaques* from Pepsodent used as a dentifrice; that this pepsin is then activated by *fermentation acid* (such as lactic acid) produced *in and under the plaques* by microorganisms; and that then the mucin plaques are digested away by the activated pepsin. But what a fantastic theory that would be? According to such a theory, the plaques must first be formed (must be there) in order to *adsorb* pepsin (meanwhile bacteria are destructively busy in and under the forming plaques). Then, the adsorption of pepsin in *effective proportion* takes considerable time, if the pepsin must be obtained from small amounts of Pepsodent used several times daily as a dentifrice (meanwhile bacteria continue to be destructively bus in and under the plaques). Finally, with the plaques in place and

pepsin adsorbed in effective proportion, fermentation acid (produced by the imbedded organisms) must be *present* at the *surfaces* of the plaques, in proportions sufficient to activate the pepsin *there*. But, of course, as fermentation acid forms, in and under a dental mucin plaque, it tends just as rapidly to *react with the enamel*, or *salivary secretions*, or both, and thus to disappear (or diminish below the effective peptic *activation proportion*), by *neutralization;* and, as such acid *continues* to be replaced by the action of the organisms in the plaque, the acid continues just as rapidly to disappear by combining with bases in the enamel and saliva. Thus, much acid may be produced but its *proportion* may be ineffective continuously. A dog chasing its tail, and getting nowhere in particular, is a good dynamic illustration, in ordinary observation, of the circuitous futility of events according to any such hypothesis as the one outlined above. Those who might insist, with reference to such a theory, that there is "something in it," however, would find it much more logical to argue that a mouth-wash consisting of a relatively strong aqueous solution of pepsin, without any of the other ingredients of Pepsodent, would be far better (and much cheaper) as a dentifrice, than Pepsodent, because the pepsin in such a solution could be presented more favorably for its universal distribution in the mouth, and its more rapid and effective adsorption there (presumed in the theory) on all the plaques that might be deposited on the teeth.

Method B

Method A results, in effect, in (a) lifting the pepsin out of a tubeful of Pepsodent after the pepsin has been attached to (adsorbed by) the protein used as a peptolytic (digestive) indicator, (b) thus getting rid of everything else in Pepsodent, and then (c) substituting a very strong activator (11 per cent lactic acid solution) for the useless so-called activator in Pepsodent (acid calcium phosphate, 1.04 per cent). In this special way, these particularly favorable laboratory conditions, which are unlike those in the mouth, show simply the presence of *some* pepsin in Pepsodent, without throwing any light on the question of the power of the pepsin to act while it is *in* Pepsodent, or when the latter is used as a dentifrice.

Method B results, in effect, in (a) removal of the abundance of tri-*basic* calcium phosphate ("the abrasive") from the contents of a tube-ful of Pepsodent, (b) thus getting rid of a substance that neutralizes acids and acid salts, *and interferes with the activation of pepsin*, and, (c) *ignoring the substance present with the pepsin and which is said (in the advertisements) to be an effective activator of the pepsin in Pepsodent* (acid calcium phosphate), then (d) adding a large excess of 0.3 per cent hydrochloric acid solution to activate the pepsin associated with the *inactive* "activator," acid calcium phosphate. In this special way, unlike conditions developed in the mouth when Pepsodent is used as a dentifrice, these particularly favorable influences result in showing simply the presence of *some* pepsin in Pepsodent, without throwing any light on the question of the power of the pepsin to act while it is *in* Pepsodent or when the latter is used as a dentifrice.

The reader of the description of Method B will note particularly that, after the mixture of a tubeful of Pepsodent with 75 cc. of water has sedimented (in 72 hours), "10 cc. of the clear supernatant fluid" (the volume used in each test) contains approximately one-tenth of the amount of pepsin and one-tenth the quantity of acid calcium phosphate in a tubeful of Pepsodent. Surely, if the acid calcium phosphate in Pepsodent effectively activates the pepsin in Pepsodent, then 10 cc. of the clear supernatant fluid would digest 10 grams of undried egg-albumen without the addition of 0.3 per cent hydrochloric acid solution or of any other activator. Why, then, the prescribed addition of this acid? If "10 cc. of the clear supernatant fluid" in a *test tube* fails to show digestive power on protein, *without the aid of an excess of fairly strong hydrochloric acid* as an additional and effective activator, how can similar fluid from Pepsodent *in the mouth* accomplish, unaided by such acid, the digestion of mucin in dental plaques that is claimed for Pepsodent in the advertisements?

Method B shows, in effect, that the author of the Pepsodent "Bulletin" (a) *declined to rely on the advertised power of acid calcium phosphate effectively to activate the pepsin* in 10 cc. of the clear supernatant fluid (free from "the abrasive"); that he then (b) proceeded wholly to ignore the so-called activator, acid calcium phosphate, in that fluid; and that he (c) added to that fluid something he knew *would* certainly activate, and activate effectively, whatever pepsin was present.

One wonders why the Pepsodent "Bulletin" did not show that the supernatant fluid, obtained from Pepsodent by Method B, is able to digest protein (mucin particularly) without the aid of anything, *for this supernatant fluid is analogous to the fluid formed in the mouth when Pepsodent is used as a dentifrice.* Here was an opportunity to demonstrate something more than the mere presence of *some* pepsin in Pepsodent. The author of the "Bulletin" had an opportuniy to show that the acid calcium phosphate in Pepsodent, in harmony with the claims in the Pepsodent advertisements, does effectively activate the pepsin in Pepsodent under conditions analogous to (but more favorable than) those that obtain when Pepsodent is used as a dentifrice.

There is no allusion in the Pepsodent "Bulletin" to the fact that Franke and Gies found that their equivalent of this "clear supernatant fluid" was so feebly peptic in digestive power on mucin that this power was practically insignificant.[2] Franke and Gies also stated in this connection a significant fact to which the "Bulletin" does not refer in any way. They said (p. 364): "The slight degree of peptic digestive power that Pepsodent is slowly able to exercise . . . is completely suspended by the addition of such proportions of saliva as would ordinarily be mixed in the mouth, with the quantities of Pepsodent used to clean the teeth."

The Pepsodent "Bulletin" disproves nothing that Franke and Gies have shown—it merely ignores what they demonstrated that is unfavorable to the Pepsodent claims. The Pepsodent "Bulletin" is devoted to the presentation of evidence that Pepsodent *contains* pepsin. This has never been denied. Franke and Gies said in this connection (loc. cit., p. 364): "Pepsodent contains pepsin or something that, under particularly favorable *laboratory* conditions, behaves very feebly like pepsin." "Bulletin No. 4" has merely described methods that institute "particularly favorable *laboratory* conditions" in this connection. Under such conditions, it was shown that Pepsodent contains pepsin that is "feebly" peptolytic.

The dental profession wants to know whether Pepsodent, *used as a dentifrice*, removes dental mucin plaques by *digesting* such plaques, and whether the specific claim to this effect, in the Pepsodent adver-

[2] Franke and Gies: *Journal of the Allied Dental Societies*, 1917, xii, p. 360.

tisements, is true and demonstrable. The dental public is not interested in the academic question whether Pepsodent merely *contains* pepsin. That may be admitted; but what of it, if the pepsin *does* nothing when Pepsodent is *used as a dentifrice?* Does the contained *pepsin* do what the promoters of the sale of Pepsodent claim and advertise that that pepsin accomplishes when Pepsodent is used as a dentifrice? That's the question. Our answer to that question is No. We find that the *pepsin* in Pepsodent will not accomplish in the mouth what is claimed for it, in Pepsodent advertisements, when Pepsodent is *used as a dentifrice.*

The "conclusions" summarized in "Bulletin No. 4"

The six conclusions summarized at the end of Pepsodent "Bulletin No. 4" were quoted above (page 303). Of these only the first three are important in this relation. These three conclusions affirm, in effect, that (a) Pepsodent contains *pepsin*, and that the pepsin in Pepsodent (b) "is in an *active* state" and (c) *capable* of digesting egg-albumen.

That Pepsodent contains *pepsin* has not been denied. That the pepsin in Pepsodent "is in an active state" is true to a material degree only if by the phrase, "active state," is meant: *capable of being rendered active.* The experiments described in the "Bulletin" show nothing more than that the contained passive pepsin may be *rendered* active (by such special means as those of Methods A and B). That the pepsin in Pepsodent is capable of digesting egg albumen was shown to be true of that pepsin only after its separation from Pepsodent and its special activation with 11 per cent lactic acid solution, in one series (Method A); and after the removal of all the tri-*basic* calcium phosphate ("the abrasive") from Pepsodent and special activation of the pepsin with 0.3 per cent hydrochloric acid solution, in another series (Method B).

The Pepsodent "Bulletin" does not discuss experiments performed with Pepsodent directly, in the form in which that dentifrice is used in the mouth. The "conclusions" are significantly silent on this point. The fifth conclusion might seem to be an exception to this statement. In that conclusion it is asserted "that Pepsodent, after

nearly three years, possesses all its proteolytic (digestive) power." The allusions to the experiments on which this conclusion is predicated, however, show clearly that the author means to indicate in this relation, not that three-year-old *Pepsodent* possesses digestive power but that *the pepsin* in such Pepsodent, when that pepsin is specially activated (by Method A or B) *outside* of, and *separated* from, Pepsodent, exhibits digestive action.

IV. GENERAL REMARKS

The title of Pepsodent "Bulletin No. 4" is: "The proteolytic power *of pepsin* in Pepsodent." One notices that the title does not refer to "the proteolytic power *of Pepsodent*." The title of the "Bulletin" would have been more accurate and more direct than it is, if it had been worded: The proteolytic power of the pepsin in Pepsodent, after the separation of that pepsin from Pepsodent (where it is practically inactive), and after the special activation of that separated pepsin with a proportion of free acid that never occurs in the plaques on the teeth.

I have never seen a statement in any journal, exclusive of ordinary advertisements, of the results of a study of the proteolytic (peptic digestive) power of Pepsodent that supported the claims of the Pepsodent Company in this connection. It seems singular, that, if Pepsodent is the powerful digestant of mucin plaques that it is said to be, and if Franke and Gies are in error in their contention that Pepsodent is not such a digestant when used as a dentifrice, no one has independently demonstrated that the Pepsodent Company is right and Franke and Gies are wrong. Three years have passed since our first publication on this subject. Is no one, outside of the Pepsodent Company's laboratories, disinterested enough to show, in the public service, that Pepsodent, purchased in the open market, is the powerful *digestant* of dental mucin plaques that the promoters of its sale claim it to be? Are not the *dental* editors of dental journals, that publish the Pepsodent claim to this effect, willing to demonstrate their loyalty to truth in advertising by showing that the facts in their editorial possession justify continuance of their publication of what Franke and Gies have found and publicly stated to be erroneous?

V. CONCLUSIONS

Pepsodent "Bulletin No. 4," issued in July, 1919, presents data to show that Pepsodent *contains* pepsin (which has not been disputed) but fails to show that this pepsin is capable of exerting any digestive action while it is present in Pepsodent, or in Pepsodent mixed with water or saliva, or both. The "Bulletin" fails to show anything directly regarding the digestive power of Pepsodent on dental mucin plaques *when Pepsodent is used as a dentifrice.*

An easy opportunity to show, in the use of Method B, that the Pepsodent Company *knows* that the acid calcium phosphate in Pepsodent effectively activates the pepsin in Pepsodent, in accordance with the Company's advertised claim to this effect, was not embraced by the author of "Bulletin No. 4." Instead of acid calcium phosphate, he used, for this purpose, *even in the presence of acid calcium phosphate*, an addition of either strong lactic acid or strong hydrochloric acid solution.

Pepsodent "Bulletin No. 4" does not refute any of the criticisms of Pepsodent that have been published by Franke and Gies—it merely ignores them.

VI. CUMULATIVE SUMMARY OF FINDINGS[3]

Mennen's Cream Dentifrice. The advertised claims that, *used as a dentifrice*, Mennen's Cream Dentifrice is (a) acid in reaction and that, (b) through the agency of acidity, this dentifrice "softens and breaks down deposits of tartar and . . . . mucin 'plaques,'" and "stimulates the flow and (increases the) alkalinity of saliva," *are claims that are wholly unwarranted.* Karshan and Gies. JOURNAL OF DENTAL RESEARCH, 1920, ii, p. 293. *Findings in support of the advertised claims stated above:* Asserted only in promoters' advertisements; no other confirmatory findings are known to the authors named above.

Pepsodent. The advertised claims that, *used as a dentifrice*, Pepsodent (a) completely removes mucin plaques from teeth, and (b) effectively prevents re-formation of such plaques on teeth, by a digestive action of

[3] A summary of findings is appended to each of the papers in this series. These summaries are cumulative, in the sense that each includes the summaries of the papers preceding it. This plan enables us to present, recurrently, the sum of the findings in this series of investigations.

contained pepsin, "activated" by admixed acid calcium phosphate, *are claims that are wholly unwarranted.* (1) Gies: *Journal of the American Medical Association*, 1917, lxviii, p. 1278 (reprinted in the JOURNAL OF DENTAL RESEARCH, 1919, i, p. 507); (2) Franke and Gies: *Journal of the Allied Dental Societies*, 1917, xii, p. 360; (3) Franke and Gies: JOURNAL OF DENTAL RESEARCH, 1919, i, p. 511; (4) Gies: JOURNAL OF DENTAL RESEARCH, 1920, ii, p. 299. *Findings in support of the advertised claims stated above:* Asserted only in promoters' advertisements; no other confirmatory findings are known to the authors named above.

EXPERIMENTAL STUDIES OF THE VALIDITY OF ADVERTISED CLAIMS FOR PRODUCTS OF PUBLIC IMPORTANCE IN RELATION TO ORAL HYGIENE OR DENTAL THERAPEUTICS

5. May the Use of Pebeco Tooth Paste, Twice a Day, Be Reasonably Regarded as a Part of "the Basis of Correct Oral Hygiene?"

PART I. PRELIMINARY TESTS OF THE RELATIVE TOXICITY OF POTASSIUM CHLORATE FOR TADPOLES AND NEWTS

WILLIAM J. GIES

Biochemical Laboratory, Schools of Medicine and Dentistry, Columbia University, New York City

CONTENTS

I. Introduction..... 313
II. Experimental (plan, methods, data)..... 315
III. Summary of the results of the tests..... 317

I. INTRODUCTION

The following statement, from a Pebeco advertisement, was quoted, and its truth denied, in a paper entitled "Highfalutin Dupery," published recently in this JOURNAL: "*Pebeco Tooth Paste twice a day and a visit to the dentist twice a year are the basis of correct oral hygiene.*"[1]

In their denial of the validity of this advertised claim for Pebeco, the authors of "Highfalutin Dupery" quoted, from the writings of "recognized authorities," various statements to the effect that an "overdose of potassium chlorate is (a) an active poison" (*U. S. Dispensatory*); that, "as a poison, potassium chlorate (b) has frequently caused death" (*Wood*); that (c) poisoning from potassium

[1] Taylor, Greeley, Limerick, Merritt, Stillman, Hyatt, Buckley and Carney: *Journal of Dental Research*, 1919, i, p. 503.

chlorate very frequently occurs from the swallowing of portions of its solutions "given for gargling" (*Sollmann*) and has been manifested in a number of deaths resulting from the absorption of potassium chlorate "when applied in solution or in substance to the oral mucous membrane" (*Prinz*); that clinical observation has shown that (d) the continued use of a tooth paste containing 50 per cent of potassium chlorate "produces inflamed and easily bleeding gum margins" (*Prinz*); and that (e) dental pastes containing 10 to 50 per cent of potassium chlorate "should not be applied to the mucous membrane of the mouth, as harm is likely to follow" (*Buckley*).

On the basis of the authoritative statements abstracted above, the authors of the paper on "Highfalutin Dupery" made the following general assertion: "Despite the fact that chlorate of potash is *an extremely dangerous drug, death often resulting from its unguarded use*, it is the chief constituent of an increasing number of dentifrices that are sold to the public with deliberate suppression of the information that *grave perils attend their employment.*"

Since potassium chlorate is "the chief constituent of an *increasing* number of dentifrices," and because dentifrices containing potassium chlorate have been publicly condemned by the distinguished authors of the paper alluded to above, it is obvious that a thorough *experimental* study of the toxicity of potassium chlorate, from the standpoint of the use of this substance *in dentifrices*, is very desirable and would be particularly opportune at this time. Accordingly, I began, as soon as possible after the publication of "Highfalutin Dupery," an experimental inquiry into the relative status of potassium chlorate as a poison and of the validity of the general objection to its free use in dentifrices. This study is in progress and will continue for some time. The results of the first completed group of tests are of such a nature, however, as to seem to require the earliest possible publication, supported as they are by the findings in additional experiments, in other relations, already completed or about to be concluded. I present, therefore, a brief description of one of the parts of this investigation, and shall follow, in successive issues, with other units in the series.

It will be advantageous, in the presentation of the first series of results, to postpone discussion of the literature on the toxicity of

potassium chlorate. In the discussion of a later series of findings, I shall give detailed attention to the literature of the subject.

Possessing general knowledge of the content of the literature on the toxicity of potassium chlorate, but without more than casual toxicologic experience with that substance, I began this research believing, with the authors of the criticism quoted above, that the data published by various observers justified the conclusions (a) that potassium chlorate is an "*extremely* dangerous drug;" (b) that "death has *often* resulted from its unguarded use;" (c) that "*grave* perils attend the employment of dentifrices containing potassium chlorate;" and (d) that the presence of potassium chlorate in dentifrices should be prohibited. I knew that potassium chlorate has valuable *medicinal* properties. I believed, however, that, as an ingredient of a toilet preparation for the promotion of oral *hygiene*, its use was not only unjustified but a menace to the public welfare.

In this belief, I naturally expected to witness striking evidence of great toxicity in the very first of my tests of the toxicologic quality of potassium chlorate. The results of the tests force me to admit, however, that this expectation has not been realized, and oblige me to say, also, that potassium chlorate does not appear to be an "*extremely*" dangerous drug (note the emphasis on "extremely.")

Although it would be premature to discuss, in this note, the facts involved (they will be considered later), I feel it my scientific and professional duty to add, also, that I no longer believe that death "*often*" results from the unguarded use of potassium chlorate (note the emphasis on "often"), or that "*grave*" perils attend the employment of dentifrices such as Pebeco that contain it (note the emphasis on "grave").

II. EXPERIMENTAL (PLAN, METHODS, DATA)

Plan

One of the most important considerations involved in the toxicology of potassium chlorate, as an ingredient of dentifrices, is the question of its *absorbability through the oral mucous membranes*. Does potassium chlorate, introduced into the mouth in the form, say, of Pebeco, pass into and through the oral mucous membranes in sufficient

quantity, at a time or in time, to damage the membranes (and injure the person)? This question presents the crux of the whole problem under review.

Before attempting to answer this question in direct experiments on the oral membranes in the human mouth, with the numerous serious obstacles in the way of successful conduct of such experiments, it was plainly desirable to test the matter in a preliminary way along collateral lines on animals. One of the most significant and instructive procedures in this relation appeared to be experiments on the toxicity of potassium chlorate for animals that would be continuously *immersed in solutions of this substance*, and obliged to take potassium chlorate into the mouth and respiratory apparatus continually, and to eat it with their food—animals that would thus be subjected to the prolonged action of the substance in the mouth and alimentary canal, and respiratory channels, and on all the exposed membranes and surfaces of the body. Surely, if potassium chlorate is readily absorbable through animal membranes, and is extremely toxic, such experiments would demonstrate both these qualities.

Tadpoles were used for the purpose, under the conditions and with the results outlined below. A few salamanders (newts) were also included.

Methods

The animals, of different strains, ages and sizes, were obtained, in several groups, from ponds in New York City. The tadpoles were legless and weighed from about 1 to 5 grams each; some were nearly 10 grams in weight. The newts were about 1.5 to 3 inches in length. After their delivery in the laboratory, the animals were kept in tapwater in a large shallow porcelain dish until they were used in the experiments. Before they were subjected to the tests, the animals were kept under observation for several days, in every instance, in order to determine that they were normal in character and suitable for the purpose. All animals of doubtful normality were rejected.

During this period of preliminary observation, and throughout all the tests, the animals were fed small though adequate quantities of powdered cereal foods such as cracker meal, or finely macerated vegetable matter such as green cabbage, and occasionally very fine par-

ticles of washed beef mixed with powdered cereal. (The newts were also given very small tadpoles.) The food was dropped directly, once daily, into the liquid in which the animals were kept. This liquid was usually renewed daily, or once every forty-eight hours, according to variable circumstances, but often enough to prevent the development of unsanitary conditions. Under these circumstances, it was possible to keep "control" tadpoles and newts alive, and apparently normal, longer than the period of two months that elapsed from the beginning to the end of these particular tests.

The animals, selected from the general stock for a series of experiments, were kept during the tests in 500 cc. of tap-water ("control") or of solutions in tap-water, in large, uncovered, glass beakers. The controllable conditions of the experiments were kept so uniform that the only *external* variables were the imposed influences under investigation.

The experiments were conducted during the months of May and June, with animals obtained during the month of May. The purest "c.p." chemicals were used.

Data

The mortality records and further details of the tests are shown in the accompanying tables (1–6).

III. SUMMARY OF THE RESULTS OF THE TESTS

The mortality records of the tests, shown in some detail in *tables 1* to *6*, make it evident that, for the animals used in these experiments, potassium chlorate was somewhat more toxic than common salt, but much less poisonous than common soaps or sodium arsenite, and very much less destructive than mercuric chloride; it was also less damaging than potassium sulfocyanate (foot-note, table 4.)

The outstanding feature of the results was the fact that a large proportion of the animals lived, several weeks, in solutions of potassium chlorate containing 0.3 or 0.4 per cent of that substance, and that solutions of potassium chlorate containing 0.1 or 0.2 per cent of the substance were toxic to only a relatively slight degree. When it is considered that the animals were immersed in, and that their

oral and respiratory surfaces were bathed by, these solutions continuously, and that all their food contained potassium chlorate from these solutions, the results imply a relatively low degree of toxicity of potassium chlorate for the animals under observation.

TABLE 1

Mortality data for tadpoles and newts in solutions of potassium chlorate and sodium chloride. Number of animals in each test: tadpoles, 3; newts, 2. Deaths are indicated by "t" for tadpole and "n" for newt

HOUR AFTER THE BEGINNING OF THE TEST	TAP-WATER "CONTROL"	SOLUTIONS IN TAP-WATER								
		Potassium chlorate, per cent[1]				Sodium chloride, per cent[1]				
		0.5	1.0	1.5	2.0	0.25	0.5	0.75	1.0	2.0
I. Tadpoles										
2				t	2t					2t
3				2t	t					t
4		t	t							
12			t							
17		t								
21			t							
22		t								
Survivors at the end of:										
24 hours...	All	None	None	None	None	All	All	All	All	None
7 days....	All	.....	.....	.....	.....	All	All	All	All	.....
II. Newts										
3					2n					
23				n						
Survivors at the end of:										
24 hours...	All	All	All	One	None	All	All	All	All	.....
7 days....	All	All	One[2]	None[2]	.....	All	All	All	All	.....

[1] The reader is reminded that the molecular weights of sodium chloride and potassium chlorate are approximately in the relation of 1:2, so that a 1.0 per cent solution of sodium chloride contains (for a study of this kind) approximately as many molecules as a 2.0 per cent solution of potassium chlorate. For this reason the corresponding solutions were made approximately equimolecular instead of equipercental.

[2] One of the newts that survived more than twenty-four hours in the 1.0 per cent solution of potassium chlorate died on the third day; the survivor in the 1.5 per cent solution died on the fifth day.

TABLE 2

Mortality data for tadpoles in solutions of potassium chlorate and sodium chloride. Number of tadpoles in each test: 3. Deaths are indicated by "t"

DAY AFTER THE BEGINNING OF THE TEST	TAP-WATER "CONTROL"	SOLUTIONS IN TAP-WATER							
		Potassium chlorate, per cent[1]				Sodium chloride, per cent[1]			
		0.2	0.3	0.4	0.5	0.1	0.15	0.2	0.25
1					t				
2					t				
3				t					
4				t	t				
5				t					
6		t	t					t	t
Survivors at the end of 7 days...	All	Two	Two	None	None	All	All	Two	Two

[1] See foot-note 1, *table 1.*

TABLE 3[1]

Mortality data for tadpoles and newts in solutions of potassium chlorate. Number of animals in each test: tadpoles, 3; newts, 2. Deaths are indicated by "t" for tadpole and "n" for newt

DAY AFTER THE BEGINNING OF THE TEST	TAP-WATER "CONTROL"	SOLUTION OF POTASSIUM CHLORATE IN TAP-WATER, PER CENT				
		0.1	0.2	0.3	0.4	0.5
I. Tadpoles						
1				t		t
2						t
3						t
4					t	
5					t	
7					t	
12			t			
14		t				
15			t	t		
29			t			
39		t				
Survivors at the end of 64 days.....	All	One	None	One	None	None
II. Newts						
8						n
10					n	
11						n
Survivors at the end of 21 days.....	All	All	All	All	One	None

[1] See the foot-note to *table 4.*

The average resistance of the tadpoles to the action of potassium chlorate appeared to be greater in each successive experiment (2–4) and with the increase in the age of the individual animals. Note the results especially with 0.3 per cent and 0.4 per cent solutions, in tables 2–4 inclusive. A variety of probabilities suggest themselves in explanation, none of which however affects the validity or significance of the essential results.

TABLE 4[1]

Mortality data for tadpoles in solutions of potassium chlorate. Number of animals in each test: 3. Deaths are indicated by "t"

DAY AFTER THE BEGINNING OF THE TEST	TAP-WATER "CONTROL"	SOLUTION OF POTASSIUM CHLORATE IN TAP-WATER, PER CENT	
		0.3	0.4
7			t
18			t
19		t	
Survivors at the end of 31 days.....	All	Two	One

[1] The experiments referred to in *tables 3 and 4* were continued until the printer's proofs of this paper were due to arrive. The six "control" tadpoles of those two experiments were then grouped into three pairs. One pair was used as a "control" in tap-water; another pair was put into 1.0 per cent solution of potassium sulfocyanate; the third pair was transferred to 0.5 per cent solution of potassium sulfocyanate. The five tadpoles that had survived the treatment with potassium chlorate were kept in tap-water. These exchanges were made late at night. On the following morning the tadpoles in the two sulfocyanate solutions were dead; the "controls" were unaffected; and the five tadpoles that survived the treatment with chlorate in experiments 3 and 4, and had been put into tap-water, were as lively as ever.

These surprising results with sulfocyanate—a constituent of saliva—led to the following use, in this emergency, of the seven remaining tadpoles. Two of the tadpoles that had been in the strongest potassium chlorate solutions in experiments 3 and 4 were continued in tap-water as "controls." The other three were placed individually in 0.4, 0.3 and 0.2 per cent potassium sulfocyanate solutions (those that had been in the strongest solutions of potassium chlorate were put into the weakest sulfocyanate solutions). Into each of the first two of these solutions was placed, also, one of the two previous "control" animals. In these three sulfocyanate solutions, the animals that had been treated previously with chlorate died in 6, 15 and 49 hours, respectively; the two previous "controls" died in 7 and 13 hours, respectively.

Of the two animals that had served as "controls" in the last preceding test—the only ones left—one was then put into 0.2 per cent, the other into 0.1 per cent, potassium sulfocyanate solution. The tadpole in the former died in 28 hours; that in the second died in 51 hours.

These unexpected results, which show that potassium sulfocyanate is more toxic than potassium chlorate for tadpoles, will require return to this particular phase of the comparative tests of toxicity.

The results lacked uniformity in some respects. The survival of the control animals in practically every case, at the end of the period of observation, shows that the observed variability was due to differences in the resistance and reaction of the animals themselves and not to dissimilarities in the routine environmental conditions. *Lack of uniformity in the medicinal effects of potassium chlorate has frequently*

TABLE 5

Mortality data for tadpoles and newts in solutions of potassium chlorate, sodium arsenite, and mercuric chloride. Number of animals in each test: tadpoles, 2; newts, 1. Deaths are indicated by "t" for tadpole and "n" for newt

HOUR AFTER THE BEGINNING OF THE TEST	TAP-WATER "CONTROL"	SOLUTIONS IN TAP-WATER						
		Sodium arsenite, per cent		Mercuric chloride, per cent				Potassium chlorate, per cent
		0.005	0.01	0.0001	0.001	0.005	0.01	0.4
I. Tadpoles								
1							2t	
2					t	2t		
3					t			
15				t				
22			t					
23		t	t	t				
Survivors at the end of 24 hours	All	One	None	None	None	None	None	All
II. Newts								
6					n			
19			n					
Survivors at the end of 24 hours	All	All	None	All	None	.....	.....	All

been noted and has been emphasized by pharmacologists as an important element in the dangers attending the internal administration of potassium chlorate.

There were no signs of irritant action, by potassium chlorate, on the skin or oral membranes of any of the animals.

The results of these tests cannot be applied *directly* to human conditions. The data strongly suggest, however, that the dangers of poisoning in the dentifricial use of potassium chlorate are not as great

as some of the clinical data in the toxicological records suggest, and that potassium chlorate is not an "*extremely*" dangerous drug or a "*gravely*" poisonous substance.

The practical applications of the results of these particular tests to human conditions will be clearer, and can be shown more plainly, after the publication of the data in our experiments on higher animals, some of which have already been completed (and will be described in the next issue of this JOURNAL) and some of which are in progress.

TABLE 6

Mortality data for tadpoles in solutions of potassium chlorate and soap. Number of animals in the tests: one in each test. Deaths are indicated by "t"

MINUTE AFTER THE BEGINNING OF THE TEST	"CONTROLS"		SOLUTION OF SOAP IN TAP-WATER[1]						
	Tap-water	Potassium chlorate, per cent	Castile (Eimer & Amend), per cent				"Rapid-shave" (Colgate & Co.) per cent		
		0.5	1.0	0.5	0.2	0.05	0.2	0.1	0.05
15			t						
20				t			t		
25					t			t	
30									t
45						t			
Survivors at the end of 45 minutes.....	All	All	None	None	None	None	None	None	None

[1] The results with soap were a great surprise. In each case there was *prompt secretion of thick mucus from the oral region and soon thereafter from the surface of the whole body!* All of the above mentioned soap solutions were alkaline to phenolthalein. That the toxic results in the soap solutions were not due solely to the condition of alkalinity of the solutions was indicated by the following observations. Castile-soap solutions were made (in tap-water) successively to contain 0.04 per cent, 0.03 per cent and 0.02 per cent of the soap. Of these, the first two were alkaline to phenolthalein; the last was not. A tadpole, which had served as a "control" for nearly two months, was placed in this 0.02 per cent castile-soap solution (not alkaline to phenolthalein) and died during the second hour thereafter. A newt, which had served as a "control" for over a month, died, after placement in such a soap solution (0.02 per cent), during the twentieth hour thereafter. These results suggested a number of additional experiments, with soap, glycerol, and other ingredients of dentifrices, but the supply of animals having been exhausted by these tests, further work in this field was temporarily suspended. (The surprise in these results suggested the concluding tests referred to in the foot-note to *table 4*.)

Direct response to the question in the title of this paper will follow the presentation of the results of the concluding experiments. It is believed that, by that time, the experimental results will have afforded sufficient evidence to provide a completely truthful answer.

IV. CUMULATIVE SUMMARY OF FINDINGS[2]

Mennen's Cream Dentifrice. The advertised claims that, *used as a dentifrice*, Mennen's Cream Dentifrice is (a) acid in reaction and that, (b) through the agency of acidity, this dentifrice "softens and breaks down deposits of tartar and . . . . mucin 'plaques,'" and "stimulates the flow and (increases the) alkalinity of saliva," *are claims that are wholly unwarranted.* Karshan and Gies: JOURNAL OF DENTAL RESEARCH, 1920, ii, p. 293. *Findings in support of the advertised claims stated above:* Asserted only in promoters' advertisements; no other confirmatory findings are known to the authors named above.

Pebeco Tooth Paste. Preliminary experiments indicate that potassium chlorate, of which Pebeco Tooth Paste contains about 50 per cent, is *not* an "*extremely*" poisonous drug and that the use of "Pebeco" as a dentifrice is *not* attended by "*grave*" perils. (Note the emphasis on the words extremely and grave.) The studies in this relation are in progress. The reader is advised to retain an open mind on this subject, pending the publication of additional data. Gies: JOURNAL OF DENTAL RESEARCH, 1920, ii, p. 313. *Opinion recently expressed in the affirmative on the above question:* Taylor, Greeley, Limerick, Merritt, Stillman, Hyatt, Buckley and Carney: JOURNAL OF DENTAL RESEARCH, 1919, i, p. 503.

Pepsodent. The advertised claims that, *used as a dentifrice*, Pepsodent (a) completely removes mucin plaques from teeth, and (b) effectively prevents re-formation of such plaques on teeth, by a digestive action of contained pepsin, "activated" by admixed acid calcium phosphate, *are claims that are wholly unwarranted.* (1) Gies: *Journal of the American Medical Association*, 1917, lxviii, p. 1278

[2] A summary of findings is appended to each of the papers in this series. These summaries are cumulative, in the sense that each includes the summaries of the papers preceding it. This plan enables us to present, recurrently, the sum of the findings in this series of investigations.

(reprinted in the JOURNAL OF DENTAL RESEARCH, 1919, i, p. 507); (2) Franke and Gies: *Journal of the Allied Dental Societies*, 1917, xii, p. 360; (3) Franke and Gies: JOURNAL OF DENTAL RESEARCH, 1919, i, p. 511; (4) Gies: JOURNAL OF DENTAL RESEARCH, 1920, ii, p. 299. *Findings in support of the advertised claims stated above:* Asserted only in promoter's advertisements; no other confirmatory findings are known to the authors named above.

THE ENDOWMENT FUND FOR THE SUPPORT OF THE JOURNAL OF DENTAL RESEARCH

SIXTH REPORT

WILLIAM J. GIES

Subscriptions to the endowment fund for the support of the JOURNAL OF DENTAL RESEARCH have been received, since the publication of the fifth report (vol. II, p. 195), from the additional contributors named below.

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Amount of accrued interest to June 30, 1920, inclusive	113.95
Total amount of the fund	3,768.10
Expenditures from the fund	None
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It is a very great pleasure to call special attention to the generosity of the dental business men and organizations named below, who have contributed effectively to the permanent support of this JOURNAL without qualification, condition or reservation, and who have shown, by the cordiality of their specific approval, that they wish to encourage and foster the development of independent research and scientific journalism in dentistry.

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A complete list of the contributors to this fund, to the end of the year 1919, is given in the section of general matter, including the title page, for volume I. The first supplementary list for 1920 was published on page 195 of this volume.

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SCIENTIFIC PROCEEDINGS OF DENTAL AND STOMATOLOGICAL SOCIETIES

SECOND SECTION

CONTENTS

Harvard Odontological Society, Boston, Mass., January 15, 1920
Eugene B. Wyman, D.M.D., Editor xxix

A LIST OF THE NAMES OF THE ORGANIZATIONS THAT HAVE VOTED TO MAKE THE JOURNAL OF DENTAL RESEARCH THE MEDIUM FOR THE OFFICIAL PUBLICATION OF THEIR SCIENTIFIC PROCEEDINGS

ASSOCIATION OF THE ALLIED DENTAL SOCIETIES, INC.

AMERICAN ACADEMY OF DENTAL SCIENCE

MASSACHUSETTS DENTAL SOCIETY

HARVARD ODONTOLOGICAL SOCIETY

BOSTON AND TUFTS DENTAL ALUMNI ASSOCIATION

FIRST DISTRICT DENTAL SOCIETY OF THE STATE OF NEW YORK

METROPOLITAN DISTRICT OF THE MASSACHUSETTS DENTAL SOCIETY

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COLUMBIA UNIVERSITY BIOCHEMICAL ASSOCIATION

In the case of the last named organization, only the dental and stomatological parts of its proceedings will be published in this JOURNAL.

A standing general invitation is extended to dental and stomatological societies, everywhere, to add their names to the above register.

PROCEEDINGS OF THE HARVARD ODONTOLOGICAL SOCIETY

EUGENE B. WYMAN, *Editor*

Meeting held January 15, 1920. Young's Hotel, Boston, Mass. President Melville F. Rogers, D.M.D., in the chair.

Scientific proceedings. *Paper* by Benjamin Tishler, D.M.D., Boston, Mass., on "*prophylaxis*" (this page). *Discussion* not reported.

"PROPHYLAXIS"

BENJAMIN TISHLER

Boston, Massachusetts

I became seriously interested in the subject of prophylaxis about seven years ago, after listening to a talk by Dr. Fones. Later, one of his patients came under my care. I found that the condition of her mouth proved to be all that he claimed for his method. The patient, a woman about sixty years of age, was in poor physical health, with a bad case of valvular heart trouble, and was not allowed to go about unattended. (This is mentioned to indicate the nature of the systemic condition which had to be combated.) She had been a patient of Dr. Fones' for several years, before coming to Boston to live. Judging from the marked gum recession and cervical erosions, she must have shown, at one time, pronounced symptoms of alveolar pyorrhea. She informed me that she visited Dr. Fones' office regularly once a month, for prophylactic treatment, after her pus pockets were healed.

Previous to that time, I had not given much attention to the treatment of pyorrhea and none whatever to prophylaxis; I had been taught to believe that pyorrhea was incurable. The treatment as taught consisted of superficial scaling, generous use of iodine on the inflamed gums, and cleaning with a brush-wheel and pumice.

Many cases present themselves today, in the more or less advanced stages, with neglected pus pockets; inflamed, turgid gums and loose teeth;

and give a previous history of cursory cleanings of this kind at irregular intervals. Some cases (I now refer to those without any marked pyorrheal symptoms, but whose gums bleed easily "on touch") are even told that their teeth need no cleaning. A recent case that came under my observation was allowed to go, in this way, for three years, but when a prophylactic treatment was given, the disclosing solution showed a marked mucous deposit along the gingival margins and on the approximal surfaces of all the teeth. This is not surprising, for, at a first glance, many mouths seem to be well brushed; there are no calcareous deposits in sight; and mucous plaques appear only when disclosing solution is applied. In my opinion, all mouths need a systematic cleansing at frequent, stated intervals, more especially those with gums that have a tendency to bleed easily. These require monthly care, all others require attention every two months.

Dr. Fones insists on monthly visits from all his patients, but in my practice I have found it difficult to require this, particularly of those whose mouths show no pathological signs. Instead, I have adopted a compromise and insist on monthly visits from those who, in my opinion, require it; that is, the patients whose mouths show a tendency to flabbiness and rapid gathering of mucous deposits. For the rest, I arrange for visits every two months or every three months (the latter for patients between twelve and eighteen years of age). Treatments are begun as soon as the permanent teeth have fully erupted, and an appointment made a week in advance of the expected visit. A record of the time when future appointments are due is kept in a book reserved for this purpose. In the event of a cancellation, a mutual agreement is made whereby twenty-four hours' previous notice is given. Whenever this occurs, a second card is sent. Patients very rarely neglect this attention.

There is no gainsaying the fact that many men pay little or no attention to the practice of preventive dentistry, notwithstanding the "oral hygiene movement" and the many talks on the subject by competent men like Fones, of Bridgeport, and Merritt, McCall, and Stillman, of New York. In the West and in some cities of the East, however, prophylaxis is practised as a specialty, not only by qualified dental nurses but also by practitioners who devote their entire time to it. The Society of Periodontists holds regular meetings, publishes a journal, and employs its own nomenclature. Papers are read, discussed, and later published, on such subjects as the proper method of brushing teeth by patients, the disposition of the tooth-brush when not in use (to keep it as nearly aseptic as possible), the effect of malocclusion as a cause of pyorrhea, and the correction of malocclusion by grinding the occlusal planes of the teeth, in conjunction with prophylactic measures.

The neglect of prophylaxis by so many men may be ascribed to two reasons. One is the fact that our dental schools do not lay stress enough upon it or give it enough importance to impress it on the minds of the students—it is treated as a by-subject rather than as a basic one, if I may use these terms. The other reason is the disinclination of many practitioners to render service of this kind, either because the kind of work does not appeal to them, or because they will not demand a suitable fee for the amount of time required to do the work thoroughly in order to get satisfactory results. Patients who have had the importance of regular prophylaxis explained to them are always grateful for the results that follow, and never fail to continue the treatments. Dentists who practise prophylaxis find their day's work made easier because the frequent visits of their patients preclude the development of painful cavities.

Under ideal conditions, that is, with the coöperation of the patients in the careful brushing of the teeth, the use of the dental floss after meals, and the rinsing of the mouth with lime-water (all of which Dr. Fones advocates), no cavities should develop. But in all cases, even in those that do not observe these procedures faithfully, the formation of cavities is greatly lessened.

It is safe to say that no branch of our work is more important, or has more far-reaching results, than prophylaxis, for, like all fundamentals, its neglect is followed by all the pathology that we constantly combat. It is incongruous to associate a clean mouth and perfectly healthy, well polished gum margins with pus pockets and erosions. If the men to whom I have referred were to give prophylaxis a trial, I am sure their enthusiasm would be aroused, for, as a method, it is not as trying as many other duties that we perform, and requires only patience and a degree of skill that is not difficult to acquire. They would be amazed to note the improvement a few treatments always produce, even in advanced cases, and would immediately realize that the employment of the engine, brush-wheel, rubber cup, or wood-point carrying pumice, is as obsolete as that of the flint-lock musket would be in modern warfare, and should be discarded for the use of the disclosing solution, polishing powder, wood-point, and ribbon-floss, applied by hand.

A prophylactic treatment should be begun by placing on the tray, in front of the patient, two small dishes, one containing disclosing solution (composed of iodine and glycerine), the other a mixture of polishing powder and water at a creamy consistency. I prefer Kuroris powder (which contains silex as a base mixed with sodium bicarbonate, powdered castile soap and a flavoring element, usually wintergreen) to pumice, for the former

is not gritty. A Kelly polisher, with a wood-point in each end, is next placed on the slab. I prefer to make my own points of orange wood, and shape them as desired, in preference to those purchased of a dental depot, for they can be made smoother by means of sand paper and more durable as well. A small swab is made with a tooth-pick and cotton and laid across the top of the dish containing the disclosing solution, *not in it.* The swabs are discarded after use on one patient, but the wood-points are cleaned after use, sterilized, and employed for many treatments. Ribbon-floss, preferably medium width, is cut into six lengths—three of 4-inch length for the anterior teeth, and three of 6-inch length for the rest—and laid close by for future use. Unless the teeth are unusually close, or the mucous deposits heavy, six lengths as described are sufficient for the approximal cleansing. Two glasses of tepid water, in which a pleasant wash is mixed, are next placed directly in front of the patient, completing the preliminary preparations.

Assuming that the calcareous deposits have been mechanically removed from the teeth, the cotton-swab is dipped into the disclosing solution and from two to four teeth covered with it from the gingival margin to the cutting edge. The patient is asked to rinse the mouth, after which the mucous deposits can be seen stained by the solution. The wood-point is dipped into the polishing cream and the entire surface of each of the stained teeth thoroughly rubbed, particularly along, and just under, the free margin of the gums, care being taken to do this in such a way as not to push it back. After this is done, disclosing solution is again applied to the same teeth, and the rinsing and polishing repeated. The process is continued until no stain remains after repeated staining and rinsing, when another group of teeth is treated in the same way. After the labial and buccal surfaces are cleaned, the lingual surfaces are treated in the same manner. Only the approximal surfaces remain unpolished. To reach these, the ribbon-floss is used. A special effort should be made with these surfaces, for we know that the greatest amount of pathology occurs there, particularly at the gingivae.

When the operation is complete, the teeth are given a general coating of the disclosing solution and the mouth thoroughly rinsed to make sure that no surface has been neglected. When this is accomplished, the teeth will have a lustre and smoothness that cannot be attained by any other method.